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eWork and eBusiness in Architecture, Engineering and Construction

Edited by Alain Zarli & Raimar Scherer

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eWORK AND eBUSINESS IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION

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eWork and eBusiness in Architecture, Engineering and Construction

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Preface

The value-adding role of product and process modelling as well as information and communications technologies (ICT) in the facilitation of information and knowledge exchange in collaborative projects and distributed teams is nowadays widely acknowledged. Even if in the past, the construction industry at large has been slow compared to other manufacturing industries in the adoption of agreed reference models, standards and ICT solutions, it is nowadays largely improving, with a clear evidence of this situation provided by the current developments in IAI and Building SMART initiatives. But still the AEC is in need for solutions that enhance the practice in general while giving equal consideration to people, processes and technology, increasing exchange and interactions across software applications and beyond organisational boundaries, and therefore addressing the lack of automation and full interoperability in design, analysis, simulation, engineering, production and fabrication, construction, operation and maintenance processes.

One of the key challenges of the construction sector is to better manage and assimilate an increasing amount of information, and indeed associated models, throughout the building lifecycle in order to reduce mistakes, improve process efficiency, enhance the potential for productivity among distributed teams, and reduce overall life-cycle product costs. This business case is common to the whole European construction industry and around the world, and is shared by other industrial sectors as e.g. Telecommunications, Automotive, Aerospace, Process Plant. Future modelling must support processes optimisation, extended products and future services for the built environment (real-estate, buildings, underground constructions, networks, etc.), and must be accompanied by the appropriate development and deployment of ICT to support these items. Especially, there is a recognised requirement to providing and generalising new methodologies, models and tools to:

- support end-user-oriented collaborative design and co-conception in the complex activity of the design process, where the evolution of the designed object is sequenced by a whole set of stages and phases, which are not necessarily linear;
- support sustainable construction industry processes, ensuring more and more efficiency in processes based on improved methodologies and indicators (e.g. BEQUEST – www.surveying.salford.ac.uk/bqextra/), CRISP – http://crisp.cstb.fr/, TISSUE – http://europa.eu.int/comm/research/fp6/ssp/tissue_en.htm), and support to decision-making for value-driven products and services, products for sustainable built environment (i.e. smart buildings, smart cities, smart tunnels, smart networks) and sustainable communities of stakeholders (people) in the Construction industry;

Electronic business activity is less developed in the construction industry than in manufacturing sectors. There are a multitude of standards, technical specifications, labels, and certification marks. The construction industry has yet to show the same level of ICT driven improvement of productivity as in other industries. This can partly be explained by the nature of the work and the type of production involved in construction processes. It is also related to slow uptake of ICT in a sector which is dominated by SMEs.

At the same time, the Construction industry is from now on facing a paradigm shift, as it is already the case in other industries like automotive for instance: a move from simple "physical" components and products towards extended IT-aware products embedding various forms of "intelligence", e.g. information and devices that aim at supporting services designed to facilitate management of life cycle performance and to meet changing end user needs, and with a clear customer orientation. Semantic engineering is there to be continuously developed as an ICT-based approach for distributed engineering leading to a fast and flexible production of customised but industrialised complex solutions with embedded intelligence. This approach would especially rely on an extensive use of semantic construction objects and pre-defined design models/reference designs.

Digital models, the so-called BIMs – Building Information Models, can serve as an efficient means for sharing rich semantic building information across different functional disciplines and corresponding software applications. They are key underlying assets for shared information between simulations and visualisations supporting performance visualisation, nD digital visualisation, and generation of manufacturing information on demand. Moreover, *standard* models are to be the mortar between the bricks of *open information-integrated systems*, *open semantic information spaces and "inter-operable" services* to all stakeholders involved at any stages of the Construction process. Digital models will allow the capture of requirements from the client, end-users, and other relevant stakeholders; the efficient and effective use of various resources needed to deliver and operate a building and the whole facility including human resources, supply chain, financial aspects and costing; the process and product compliance with regulations across the building and facility lifecycle; the selection of sustainable product components achieving best performance and "buildability"; and the overall improved management of facility assets during the exploitation while improving its global impact on the environment.

Product and process modelling has been recognised as a key topic for future RTD in Strat-CON thematic roadmaps supporting the ECTP Focus Area 7 (Processes & ICT), and being the basis for the "Automated Design" element in the FIATECH Capital Projects Technology Roadmap. As a universal delivery vehicle for the built environment's information, digital models are to support:

– Knowledge Sharing and Collaboration – offering means for advanced knowledge capture and representation and for effective knowledge search and easy access to relevant information while improving collaboration and the decision-making process;
– Interoperability, communication and cooperation – to seamlessly exchange pertinent information with each other and between all ICT-based applications, and to deliver solutions that facilitate communication and collaboration between geographically dispersed actors located in different companies in different time zones with different responsibilities, different cultures, etc.;
– Supply Chain and Demand Network Management – being a pillar for just-in-time delivery, not only of materials and equipment, but also of labour and information, as a determinative factor in the time and financial planning of capital construction projects;
– Value-driven Business models – with expansion of BIMs from design phase to include both user dialog before design, production, and user dialog after design, and the ability to communicate between different stakeholders with different interests and professional backgrounds.

The ECTP SRA (Strategic Research Agenda) has also identified intelligent ambiance and smart constructions as a key research theme to improve our living environments in terms of comfort, health and safety, as well as to achieve more energy efficient buildings and products, which is one of the biggest challenges that buildings have to meet for today and the coming years to reduce carbon gas emission and primary energy consumption. The development of the ICT systems that will support these new services need to advance research on related ICT topics such as domain-oriented building modelling, in particular energy efficiency oriented modelling, simulation, building design optimisation, management system optimisation, together with new business models.

In its role as a state-owned research establishment in the construction sector, CSTB has developed quite a lot of competencies and throughput capability in the fields of scientific and technological areas dedicated to the Built environment as a large, as well as economics and sociology. One of a key area of expertise is indeed *Information and Communication Technologies*, including interoperability, information and knowledge management and Knowledge-based systems, and digital models CSTB being an early discoverer of the need for managing structured data, information and knowledge in the early '90s through its participation to STEP and the initial development of the IFC: its long lasting interest in product and process modelling has definitely been a key incentive for CSTB in organising the ECPPM 2008 conference, in Sophia Antipolis, in the South-East of France. These proceedings reflect the current up-to-date developments and future exploration of the leverage expected from ICT deployment in undertaking AEC/FM processes, based on a selection of high quality papers, and fruitful and living sessions and dedicated workshops that have provided with detailed information on the achievements and trends in research, development, standardisation and industrial implementation of product and process information technology.

A conference like ECPPM 2008 is indeed the result of the participation and commitment of all the people taking part in it: we would take the opportunity of the conclusion of this preface to warmly thank the conference organising committee, the Scientific committee members, all CSTB actors having provided their encouragement, the Institute of Construction Informatics at the Technical University Dresden for their support in compiling this book, and of course all the authors and attendees of the conference.

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Advanced ICT under the 7th EU R&D framework programme: opportunities for the AEC/FM industry

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ABSTRACT: The 7th EU framework programme for research (FP7) aims to provide new impetus to Europe's growth and competitiveness, in realising that knowledge is Europe's greatest resource. The programme places greater emphasis than in the past on research that is relevant to the needs of European industry, to help it compete internationally, and develop its role as a world leader in certain sectors. For the first time the framework programme provides support for the best in European investigator-driven research, with the creation of a European Research Council. The FP7 budget is 50% higher compared with its predecessor.
The paper focuses on advances in information and communication technologies (ICT) under FP7 and on how the architecture, engineering and construction (AEC) industry and facility management (FM) can benefit through a systematic involvement. The technologies under development, ranging from wireless sensor networks, cooperative smart objects, plug-and-play control architectures, technologies supporting the "Internet of Things", to ICT services supporting energy efficiency can benefit not only this sector, but the economy as a whole.
Significant industrially relevant research will be carried out in the two ICT Joint Technology Initiatives (JTI) which are launched in 2008. They address nanoelectronics and embedded computing systems applications. In international cooperation, the Intelligent Manufacturing Systems (IMS) initiative is focusing its strategy on building Manufacturing Technology Platforms in areas such as standardisation, education, sustainable manufacturing, energy efficiency and key technologies. All these activities aim to link R&D efforts of research groups across sectors, countries and regions.

1 INTRODUCTION

The 7th research framework programme, from 2007-2013, was designed to respond to the competitiveness and employment needs of the EU. Its budget is higher by 60 % compared to FP6, rising to EUR 54 billion (FP7, 2006).

FP7 activities consist of four specific programmes (Figure 1). The new 'Ideas' programme aims to foster scientific excellence. An independent European Research Council has been created to support "frontier research" carried out by research teams competing at European level either individually or through partnerships, in all scientific and technological fields, including the social and economic sciences and the humanities.

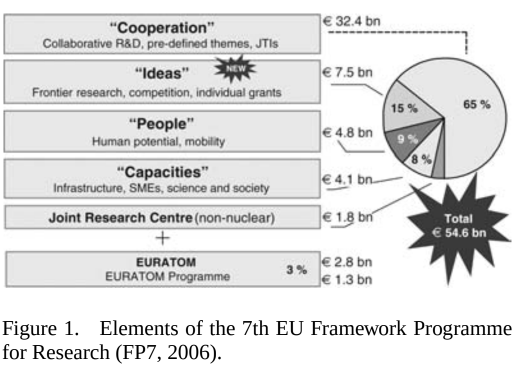

Figure 1. Elements of the 7th EU Framework Programme for Research (FP7, 2006).

The 'People' programme supports scientific careers of researchers through training and mobility activities.

The objective of the 'Capacities' programme is to develop the best possible research capacities for the European science community.

Activities of this programme aim to enhance research and innovation capacity in Europe, e.g. via research infrastructures and the building up of regional research clusters ('regions of knowledge'), by engaging in research for and by SMEs, through 'science in society' activities and international cooperation.

The 'Cooperation' programme is the largest specific programme with a budget of EUR 32.3 billion. It promotes Europe's technology leadership in specific areas mainly through collaborative industry-academia partnerships. The programme is subdivided into ten themes

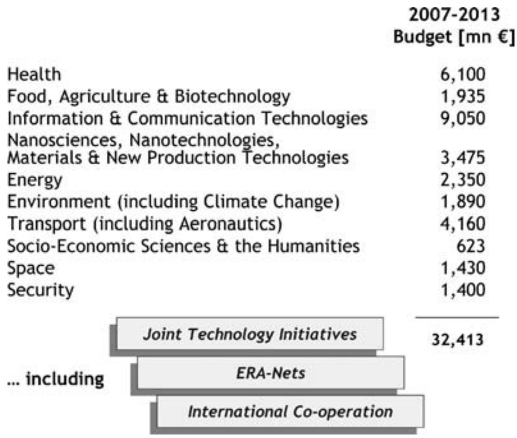

Figure 2. The 10 Themes of the Specific Programme "Cooperation" (FP7, 2006).

(Figure 2) which are operating autonomously, allowing for joint, cross-thematic approaches on research subjects of common interest.

2 EUROPEAN INDUSTRY-ACADEMIA COLLABORATIONS FOSTERED BY SUCCESSIVE FRAMEWORK PROGRAMMES

Collaboration is a key in the knowledge age. Europe, after centuries of war, has become a peaceful and prosperous area, also due to a spirit of collaboration that has successfully been built up in the past fifty years and the successful implementation of research cooperations.

2.1 *'Cooperation culture' – A European asset*

For centuries, Europe had been the scene of frequent and bloody wars. In the period 1870 to 1945, France and Germany fought each other three times, with a terrible loss of life. European leaders gradually became convinced that the only way to secure lasting peace between their countries was to unite them economically and politically.

So, in 1950, in a speech inspired by Jean Monnet, the French Foreign Minister Robert Schuman proposed to integrate the coal and steel industries of Western Europe. As a result, in 1951, the European Coal and Steel Community (ECSC) was set up, with six members: Belgium, West Germany, Luxembourg, France, Italy and The Netherlands. The power to take decisions about the coal and steel industry in these countries was placed in the hands of an independent, supranational body called the "High Authority". Jean Monnet was its first President.

The ECSC was such a success that, within a few years, these same six countries decided to go further and integrate other sectors of their economies. In 1957 they signed the Treaties of Rome, creating the European Atomic Energy Community (EURATOM) and the European Economic Community (EEC). The member states set about removing trade barriers between them and forming a "common market". In 1967 the institutions of these three European communities were merged. From this point on, there was a single Commission and a single Council of Ministers as well as the European Parliament. Originally, the members of the European Parliament were chosen by the national parliaments, but in 1979 the first direct elections were held, allowing the citizens of the member states to vote for a candidate of their choice. Since then, direct elections have been held every five years.

The Treaty of Maastricht (1992) introduced new forms of co-operation between the member state governments – for example on defence, and in the area of "justice and home affairs". By adding this inter-governmental co-operation to the existing "Community" system, the Maastricht Treaty created the European Union (EU). Economic and political integration between the member states of the European Union means that these countries have to take joint decisions on many matters. So they have developed common policies in a very wide range of fields – from agriculture to culture, from consumer affairs to competition, from environment and energy to transport, trade and research.

In the early days the focus was on a common commercial policy for coal and steel and a common agricultural policy. Other policies were added as time went by, and as the need arose. Some key policy aims have changed in the light of changing circumstances. For example, the aim of the agricultural policy is no longer to produce as much food as cheaply as possible but to support farming methods that produce healthy, high-quality food and protect the environment. The need for environmental protection is now taken into account across the whole range of EU policies.

It took some time for the member states to remove all barriers to trade between them and to turn their "common market" into a genuine single market in which goods, services, people and capital could move around freely. The Single Market was formally completed at the end of 1992, although there is still work to be done in some areas – for example, to create a genuine single market in financial services.

During the 1990s it became increasingly easy for people to move around in Europe, as passport and customs checks were abolished at most of the EU's internal borders. One consequence is greater mobility for EU citizens. Since 1987, for example, more than a million young Europeans have taken study courses abroad, with support from the EU.

The EU has grown in size with successive waves of enlargement. Denmark, Ireland and the United Kingdom joined the six founding members in 1973, followed by Greece in 1981, Spain and Portugal in 1986 and Austria, Finland and Sweden in 1995. The European Union welcomed ten new countries in 2004: Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. Bulgaria and Romania followed in 2007; Croatia and Turkey have begun membership negotiations. To ensure that the enlarged EU can continue functioning efficiently, it needs a more streamlined system for taking decisions. That is why the agreement reached in Lisbon in October 2007 lays down new rules governing the size of the EU institutions and the way they work (Filos, 2008).

2.2 *More than 20 years of European collaborative research*

In many cases it can be more advantageous to collaborate than to "go it alone". Some research activities are of such a scale that no single country can provide the necessary resources and expertise. In these cases, collaborative R&D projects under the European framework programme for research can allow research to achieve the required "critical mass", while lowering commercial risk and producing a leverage effect on private investment (FP7, 2005). These projects establish international consortia that bring together resources and expertise from many EU member states and research actors. An average EU shared-cost project has a budget of EUR 4.5 million and involves on average 14 participants from 6 countries, bringing together universities, public research centres, SMEs and large enterprises.

European-scale actions also play an important role in transferring skills and knowledge across frontiers. This helps to foster R&D excellence by enhancing the capability, quality and Europe-wide competition, as well as by improving human capacity in science and technology through training, mobility and career development.

The increasing number of participants and rates of oversubscription provide convincing evidence that participation appeals to Europe's research community. One significant explanation for this interest is the fact that participation in collaborative research offers access to a wider network of knowledge. It enables participants to increase their know-how by being exposed to different methods, and to develop new or improved tools. Being part of an international consortium of highly qualified researchers offers spill-over effects that are more important than the monetary investment. The experience of six European framework programmes shows that while all participating countries enjoy knowledge multiplier effects, the size of these effects is roughly inversely related to the country's total number of participations in the programme.

Another feature of collaborative research is that public R&D funding carried out by enterprises leads to what is called a "crowding-in" effect on investment. In other words, it stimulates firms to invest more of their own money in R&D than they would otherwise have done. A recent study estimated that an increase of EUR 1 in public R&D investment induced EUR 0.93 of additional private sector investment. In the case of the framework programme, there is evidence that many projects would not have been carried out at all without EU funding. The consistent picture is that in approximately 60–70% of the cases the programme enables research activities to take place that would otherwise not have occurred. EU support for R&D encourages a particular type of research project, in which private companies can collaborate with foreign partners at a scale not possible at national level, in projects tested for excellence, and gain valuable access to complementary skills and knowledge. It is therefore reasonable to conclude that the attractiveness of EU schemes induces firms to invest more of their own funds than they would under national funding programmes.

Large-scale European projects enable participants to access a much wider pool of firms in a certain industry domain than would be possible at purely national level. This mechanism offers clear advantages to enterprises compared with national level schemes. It broadens the scope of research, and allows for a division of work according to each participant's field of specialisation.

It also considerably reduces the commercial risk, because involving key industry players helps ensure that research results and solutions are applicable across Europe and beyond, and enables the development of EU- and world-wide standards and interoperable solutions, and thus offers the potential for exploitation in a market of nearly 500 million people.

Many projects lead to patents, pointing to an intention to exploit research results commercially. While the propensity to patent seems to be the same for the different types of research actors, industrial participants are more likely to be involved in projects with an applied research focus than pure basic research projects. In addition to the new knowledge described in a patent, participation in European collaborative research enhances the development and use of new tools and techniques; the design and testing of models and simulations; the production of prototypes, demonstrators, and pilots; and other forms of technological development. Firms that participate in this type of research, irrespective of their size, tend to be more innovative than those that do not participate. Participating enterprises are also more likely to apply for patents than non-participants. In Germany, for example, firms funded under the framework programme make three times as many patent applications as non-participating firms. Participating enterprises are also more likely to engage in innovation cooperation with other partners in the innovation system, such as other firms and universities. Although no causal links can be 'proven' by these results, they nevertheless provide a strong indication that public funding for research strengthens innovation performance (SEC, 2004).

A wide range of ex-post evaluation studies (FP7, 2005) show that as a result of framework programme participation firms are able to realise increased turnover and profitability, enhanced productivity, improved market shares, access to new markets, reorientation of a company's commercial strategy, enhanced competitiveness, enhanced reputation and image, and reduced commercial risks.

Results of econometric modelling indicate that the framework programme generates strong benefits for private industry in the EU. A recent study in the UK, commissioned by the Office for Science and Technology, used an econometric model developed at the OECD to predict framework programmer effects on total factor productivity. It was found that the framework programme "generates an estimated annual contribution to UK industrial output of over GBP 3 billion, a manifold return on UK framework (programme) activity in economic terms" (OST, 2004).

3 ICT AND AEC/FM

Today we are witnessing the next phase of a technological revolution that started more than fifty years ago with the miniaturisation of electronic components, leading to the widespread use of computers and then their linking up to form the Internet.

The overall size of the world market in electronics was around EUR 1,050 billion in 2004 (IFS, 2005), not counting the microelectronics chips themselves, which were worth another EUR 210 billion. But even more striking is the growing share accounted for by electronics in the value of the final product: for example, 20% of the value of each car today is due to embedded electronics and this is expected to increase to 36% by 2009. Likewise, 22% of the value of industrial automation systems, 41% of consumer electronics and 33% of medical equipment will be due to embedded electronics and software.

Several areas, as described below, supply the basic components of the ICT sector and are considered a strategic part of Europe's industrial competence. Microelectronics currently represents 1% of global gross domestic product. While Intel leads the worldwide chip market, the three major European manufacturers, ST Microelectronics, Infineon Technologies and NXP (formerly Philips Semiconductors), have figured among the global top ten for the past ten years. On the chip manufacturing equipment side, ASM Lithography has become a true European success story by gaining world leadership in lithography – the technology used in chip fabrication (ENIAC, 2004).

Organic (or "printed") electronics offers new opportunities for integrating electronic, optical and sensing functions in a cost-effective way through conventional printing. First products such as electronic paper and intelligent displays printed directly onto product packages are expected to reach the market in the next two years. Organic light-emitting diodes (OLED), also based on this technology, are already in use in mobile phones. Printed electronics could revolutionise many industries as they do not require billion-Euro production facilities and so electronics manufacturing can be moved to where the customers are, thus creating new opportunities for local employment. Large-area lighting and signage applications, of utmost importance to AEC, become feasible and affordable through OLED technology. The market is forecast to have an annual growth rate of 40% over the next five years. By 2025, the business is expected to account for EUR 200 billion, almost the size of today's microelectronics industry.

Integrated micro/nanosystems draw together a broad variety of technological disciplines (electronics, mechanics, fluidics, magnetism, optics, biotechnology). It involves multiple materials and manufacturing processes. Europe leads the field in systems integration technologies in terms of knowledge generation and the challenge now is to convert this into industrial leadership. New business opportunities are emerging, both for technology suppliers and system developers. For example, in the specific area of micro-electromechanical systems (MEMS), the market is expected to double within five years, from EUR 12 billion in 2004 to EUR 25 billion in 2009 (NEXUS, 2006).

The market for electronic equipment is characterised by a constant need to bring to the users innovative products and services with increasing functional capabilities at an ever diminishing price. Embedded computing systems are of strategic importance because they underpin the competitiveness of key areas of European industry, including automotive technology, avionics, consumer electronics, telecommunications, and manufacturing automation. Intelligent functions embedded in components and systems will also be a key factor in revolutionising facility management and industrial production processes, adding intelligence to process control and to the shop floor, helping improve logistics and distribution – and so increasing productivity. The capability to deliver systems with new functional capabilities or improved quality within a competitive timeframe has ensured substantial market shares for Europe's economy in various domains. The share of embedded electronics in the value of the final product is expected to reach significant levels in the next five years: in industrial automation (22%), telecommunications (37%), consumer electronics and intelligent home equipment (41%) and applications related to health/medical equipment (33%) (MMC, 2006). The value added to the final product by embedded software is much higher than the cost of the embedded device itself.

To stay competitive Europe must increase and bundle its R&D efforts to stimulate synergies in advanced technological areas by favouring knowledge transfer from academia to industry and across industrial sectors and by encouraging the formation of new industrial clusters. It can only succeed if it acts jointly and in a coherent way.

3.1 *Electronics – key to the future of AEC*

The last twelve years have shown that Europe can achieve a lot. Consecutive European R&D framework programmes and Eureka initiatives (Eureka, 2008) have supported major research efforts and managed to bring Europe's electronics research and manufacturing, and the related materials science and equipment research, on equal level with competitors worldwide. But the efforts need to continue and even to increase if Europe wants to keep up. Consensus has grown amongst European policy makers on the added value of 'clustering' competent players around technology objectives. Some countries and regions are making significant investment in electronics by building up and sustaining research and innovation eco-zones, termed 'competitiveness poles'. These networks could lead to additional synergies if they are linked up at European level (Figure 3).

Three European technology platforms relating to electronics have been set up by industry: ENIAC (ENIAC, 2008) on nanoelectronics, EPoSS on smart systems integration (EPOSS, 2008), and ARTEMIS on embedded systems (ARTEMIS, 2008). These platforms have so far been successful in bringing together key industrial and academic research players and in reaching consensus on a long-term vision and agenda for research, delivered in the form of a strategic research agenda.

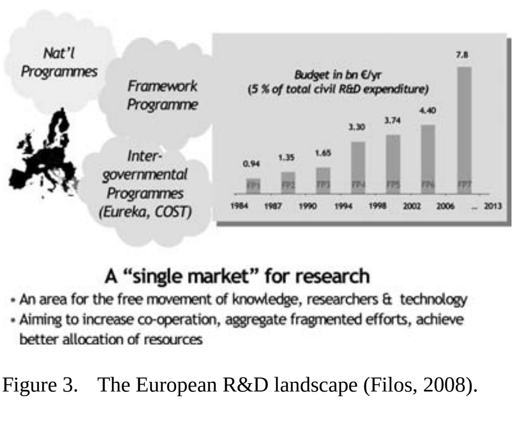

Figure 3. The European R&D landscape (Filos, 2008).

Recognising this need, the European Commission began promoting the concept of European technology platforms in 2003. European technology platforms (Figure 4) involve stakeholders, led by industry, getting together to define a strategic research agenda on a number of important issues with high societal relevance where achieving growth, competitiveness and sustainability objectives is dependent on major research and technological advances in the medium to long term (ETP, 2005).

Implementing strategic research agendas of European technology platforms (Figure 5) requires an effective combination of funding sources, including public funding at member state level and private investment in addition to European support, e.g. through the framework programmes. With regard to the European

Figure 4. European technology platforms (Filos, 2008).

Figure 5. Implementing the Strategic Research Agenda of the European Technology Platforms.

funding element, use of the regular instruments of collaborative research is likely to be the most effective way of providing Community support for the implementation of the EU-relevant parts of the majority of strategic research agendas developed by the European technology platforms. There are a limited number of technology platforms in areas that offer the opportunity for significant technological advances which have achieved such a scale and scope that implementation of important elements of their strategic research agendas requires the setting up of long-term public-private partnerships. In these cases, support through the regular instruments of collaborative research is not sufficient. For such cases the European Commission has proposed the launching of Joint Technology Initiatives (COM, 2004, 2005; SEC 2005).

The key advantage of these activities is that they help focus efforts and align activities by bringing all the relevant private and public players in Europe together. The platforms thus aim to catalyse a critical mass of competences and resources (from industry and the public sector) to undertake research following a jointly agreed strategic research agenda and to agree on other relevant issues of importance to business success, especially standards (e.g. common platforms and architectures, environment – health – security issues, SME involvement) and also skills profiles.

3.2 *The European nanoelectronics initiative advisory council – ENIAC*

A far-sighted strategy for the European nanoelectronics industry, aimed at securing global leadership, creating competitive products, sustaining high levels of innovation and maintaining world class skills within the European Union is outlined in 'Vision 2020 – nanoelectronics at the Centre of Change' (ENIAC, 2004). In addition to identifying the technological, economic and social advantages of strengthening nanoelectronics R&D in Europe, the 'Vision 2020' document highlights the importance of creating effective partnerships in order to achieve this goal. Its rationale is that Europe must not only have access to leading-edge technologies for nanoelectronics. It must also have an efficient means of knowledge transfer between R&D and manufacturing centres in order to turn this technology into leading-edge value-added products and services. Such partnerships will need to include all stakeholders in the value chain, from service providers at one end to research scientists at the other, so that research in nanoelectronics can remain strongly innovative, and, at the same time, result in technological and economic progress.

To create an environment in which these partnerships can flourish, 'Vision 2020' proposes the development of a strategic research agenda for nanoelectronics that will enable industry, research organisations, universities, financial organisations, regional and EU member state authorities and the European Commission to interact and thus provide the resources required, within a visionary programme that fosters collaboration and makes best use of European talent and infrastructures. ENIAC has been set up to define this technology platform and develop strategic research agenda. The latter describes a comprehensive suite of hardware and silicon-centric technologies that firmly underpin the semiconductor sector.

While the nanoelectronics technology platform covers the physical integration of electronic systems-on-chip or systems-in-package, the technology platform on embedded systems covers the software- and architecture-centric group of technologies in ICT. The technology platform on smart systems integration covers the technology for the physical integration of subsystems and systems for different applications. Together, these three platforms bear the potential to become key enablers for providing the underlying technologies for virtually all other major European technology platforms. Taking into account the short-, medium- and long-term challenges faced by Europe, the ENIAC strategic research agenda identifies and quantifies the performance parameters needed to measure the progress of nanoelectronics research, development and industrialisation. By setting these out as a series of application-driven technology roadmaps it provides guidance in the coordination of local, national and EU wide resources in the form of research, development, manufacturing, and educational governance, infrastructures and programmes. By matching technology push from the scientific community with the innovation of SMEs and the market pull of large industrial partners and end-users, the strategic research agenda aims to ensure that research coordinated under it will be relevant to industry, the economy and society as a whole.

3.3 *The European platform on smart systems integration – EPoSS*

Strong market competition calls for rapid product change, higher quality, lower cost and shorter time-to-markets. 'Smaller' and 'smarter' will be key requirements for systems in the future, therefore transdisciplinarity is a challenge. The miniaturisation of technologies down to the nano-scale, together with the application of the molecular-level behaviour of matter may open new opportunities for achieving ground-breaking solutions in many booming fields such as bioengineering, energy monitoring, and healthcare. In particular the ability to miniaturise and to integrate functions such as sensing, information processing and actuating into smart systems may prove crucial to many industrial applications. Perceptive and cognitive smart systems – will thus increasingly be offered in miniature and implantable devices with features such as high reliability and energy-autonomy.

The EPoSS strategic research agenda (EPOSS, 2007) has been produced by expert working groups. It lays down a shared view of medium-to-long-term research needs of industry in sectors such as automotive, aerospace, medical, telecommunications and logistics. It reflects the trend towards miniaturised multifunctional, connected and interactive solutions. Multidisciplinary approaches featuring simple devices for complex solutions and making use of shared and, increasingly, self-organising resources are among the most ambitious challenges. EPoSS therefore proposes a multilevel approach that incorporates various technologies, functions and methodologies to support the development of visionary new products. Rather than solving problems in a piece-meal approach, e.g. at the component level, it advocates a systems approach that offers comprehensive solutions. EPoSS is therefore neither dedicated to a specific research discipline, nor does it aim to restrict its activities to a certain scale or size of devices. Its goal is smart systems that are able to take over complex human perceptive and cognitive functions; devices that can act unnoticeably in the background and that intervene only when the human capability to act or to react is reduced or ceases to exist. Examples for such systems are, object recognition devices for automated production systems; devices that can monitor the physical and mental condition of a vehicle's driver; integrated polymer-based RFIDs for logistics applications etc. The target application domains of smart systems R&D – in a horizon of ten to fifteen years – are outlined in this document: (a) automotive; (b) aeronautics; (c) information technology and telecommunications; (d) medical applications; (e) logistics/RFID; (f) other cross-cutting applications.

3.4 *Advanced research & technology for embedded intelligence and systems – ARTEMIS*

Embedded technologies are becoming dominant in many industrial sectors, such as communications, aerospace, defence, building and construction, manufacturing and process control, medical equipment, automotive, and consumer electronics. This trend is likely to continue, given the ever-increasing possibilities for new applications offered by advanced communications, embedded computing devices, and reliable storage technologies. Industries using and developing embedded systems differ significantly in business and technical requirements and constraints. Development cycles of complex industrial equipment, such as airplanes, industrial machines and medical imaging equipment, but also cars, are much longer than the development cycles of other high-volume, cost-dominated devices for private customers, such as DVD players, mobile phones, ADSL modems and home gateways. Safety requirements are different for an airplane, for a car and for a mobile phone. Security, privacy and data integrity pose specific requirements in various environments. Hence, industry is increasingly requested to integrate conflicting requirements.

In construction, there are not only the traditional safety requirements, but also the requirements of facility management and equipment, with an ever increasing integration of sensing, actuating and communications capabilities into the total system of a building. However, little cross-fertilization and re-use of technologies and methodologies is happening across industrial domains, since the segmentation of markets with their specific requirements leads to a fragmentation of supply chains and R&D efforts. One of the main ambitions of the ARTEMIS technology platform is to overcome this fragmentation by cutting barriers between application sectors leading to a diversification of industry, and by enabling a cross-sectorial sharing of tools and technology.

Embedded systems do not operate in isolation, but rather in combination with other systems with the aim to realise an overarching function. Examples are: digital television integrated into the 'digital' home; medical diagnostic devices embedded in hospital environments; infrastructure such as bridges, tunnels, roads that exchange information with cars to avoid accidents. These systems are often characterised by a large-scale networked integration of heterogeneous intelligent components. Sensor networks, and even aggregations of 'smart dust', may pose, in addition to these, requirements such as operation at low power, energy harvesting, miniaturisation, data fusion, reliability and quality-of-service.

In addition to these requirements, there is also a need to undertake new and unexplored approaches to safeguard the safety, security, reliability and robustness of the embedded systems in the future. The use and integration of off-the-shelf components certainly poses an additional challenge, as these components usually are not designed from the perspective of the decomposition of the system at hand. A transition from design by decomposition to design by composition raises some of the most challenging research and development questions in the embedded systems domain today.

These changes, as well as the ambition for cross-sectorial commonality, inspire much of the specific research proposed in the ARTEMIS strategic research agenda (ARTEMIS, 2006). It outlines the objectives and the research topics that need to be addressed in the domain of embedded systems. This current strategic research agenda consists of three documents addressing issues such as (a) Reference Designs and Architectures; (b) Seamless Connectivity & Middleware; and (c) System Design Methods & Tools.

The Reference Designs and Architectures part of the strategic research agenda establishes common requirements and constraints that should be taken into account for future embedded systems when establishing generic reference designs and architectures for embedded systems that can be tailored optimally to their specific application context. The Seamless Connectivity & Middleware part addresses the needs for communication at the physical level (networks); at the logical level (data); and at the semantic level (information and knowledge). Middleware must enable the safe, secure and reliable organisation – even self-organisation – of embedded systems under a wide range of constraints.

The Systems Design Methods & Tools part of the research agenda sets out the priorities for research as to how these systems will be designed in future to accommodate and optimise the balance to achieve a number of conflicting goals: system adequacy to requirements, customer satisfaction, design productivity, absolute cost, and time-to-market.

Each part of this research agenda has been produced by a group of experts that devised their own method of working. While the three expert groups liaised to achieve coverage and avoid inconsistencies, each of the three documents has its own structure and style. All three parts are 'living' documents that will be continuously refined and updated as research results arrive over the coming years.

3.5 *Towards an "Internet of Things"?*

With more than two billion mobile terminals in commercial operation world-wide and about one billion Internet connections, wireless, mobile and Internet technologies have enabled a first wave of pervasive communication systems and applications of significant impact.

Whilst this networking trend has acquired an irreversible dimension, there is undoubtedly a new networked technology dimension emerging with the deployment of trillions of RFID tags. Today's simple tags are evolving towards smarter networked objects with better storage, processing and sensing capabilities. This is leading to new and widespread applications in many sectors. The vision of the "Internet of Things", promoted by the International Telecommunications Union (ITU), foresees billions of objects "reporting" their location, identity, and history over wireless connections in application such as building environments and logistics (ITU, 2005).

Flexibility is expected to become a key driver, enabling networks to reconfigure more easily and to dynamically adapt to variable loads and use conditions implied by an ever growing number of components and applications. New classes of networking technologies are emerging, such as self organised networks with dynamically varying node topologies, dynamic routing and service advertisement capability. Under such dynamic operational constraints, network management tools require increased adaptability and self-organisation/-configuration capability of network and service resources.

The resulting network and service architectures will need to support fully converged environments, such as extended home networks, with myriads of intelligent devices in homes, offices, or on the move providing an extensive set of applications and multimedia contents, tailored to the device, the network, and the application requirements.

Networked objects equipped with sensing and processing capability will become capable of autonomous decision-making and will collaborate to better serve user preferences and management requirements such as energy efficiency. Future intelligent buildings may engage in collaborating across domains to dynamically control energy consumption on the basis of use patterns and knowledge about deviations from standard use patterns, for example, when the heating in the home is to be turned on only when the user is in physical proximity and is not stuck in traffic.

4 CONCLUSIONS

This paper aimed to draw a picture of the changing R&D landscape in Europe. European research policy, aiming to build strong industry-academia R&D partnerships and to increase levels of R&D investment, is a proof for Europe's determination to achieve leadership in ever-competitive world markets. The 7th framework programme for research supports this goal with its objective to strengthen research excellence and to forge strong collaborative research partnerships across Europe and with international partners (IMS, 2008).

The paper aimed to provide in particular a non-exhaustive overview of the new programme's advanced ICT objectives and how these may impact the AEC/FM sector and industry as a whole. What will be essential for the success of industry-academia cross-fertilisation is the cross-sectorial interlinking and cooperation between technology-oriented platforms, such as those discussed above, with more sectorial platforms, such as the European Construction Technology Platform (ECTP, 2008).

This requires trans-disciplinary thinking and certainly an open-handed approach.

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Anatomy of a cogitative building

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ABSTRACT: This paper addresses the necessary conditions for the emergence of a cogitative building. A cogitative building is defined here as one that possesses a complex representation of its context (surroundings, micro-climate), its physical constituents (components, systems), and its processes (occupancy, indoor environmental controls). Moreover, it can dynamically update this representation and use it for virtual experiments toward regulation of its systems and states. A summary of the required key technologies and the related state of their development is presented, together with general reflections on problems and prospects of cogitative buildings.

1 INTRODUCTION

Projection of human-like attributes such as intelligence and sentience unto inanimate objects has a long tradition in myths, literature, and popular culture. The underlying motivations may be explained, in part, by psychologically based conjectures. Similar attempts in the engineering field need, however, a more utilitarian justification. One related motivation has been system complexity. The understanding and control of the behavior of complex human-made artifacts may benefit from observing and emulating behavioral and control patterns in naturally complex biological and sentient beings. Consequently, engineering systems embellished with features and capabilities that support intelligent behavior in living systems, may also display advantages in terms of optimal operation under dynamically changing boundary conditions (Bertalanffy 1976, Brillouin 1956, Wiener 1965). Accordingly, efforts to supplement buildings with intelligence, sentience, and self-awareness have often stated, as their goal, realization of buildings that can optimally meet user requirements while operating efficiently (Mahdavi 2004a). Thus, endowing buildings with human-like attributes of intelligence and sentience is not an ends in itself, but rather a means of improving buildings′ performance.

In this context, two questions arise. First, what does it mean (or what does it take) to make a building intelligent, or sentient, or self-aware, or cogitative (capable of thinking)? Second, if successfully realized, does a cogitative building perform actually and measurably better than a conventional one?

The author does not intend to provide a definitive answer to these complex questions. Nor will he make an attempt to exhaustively treat the large body of literature on research and development in this field. Rather, a specific and selective view of the concept of cogitation in the context of building design and operation is presented and consequently examined in view of its technical feasibility and promise. This specific view is primarily informed by the previous research performed by the author and his research team, explaining the present paper's high frequency of self-quotations.

2 DEFINITION

Recent advances in information and sensor technologies have given rise to frequency and consistency of efforts to augment conventional buildings via implementation of pervasive sensing infrastructures and intelligent control devices and methods. This, however, has not resulted in a consensus as to the exact nature of those intrinsic features that make a building intelligent, or – as suggested in a number of the author's previous publications – self-aware, or sentient (Mahdavi 2004a, 2001a).

The gist of these suggestions may be summarized as follows. A critical (not necessarily sufficient) condition for a cogitative system is the presence of a representational faculty. According to this view, a system capable of cogitation must have at its disposal a dynamic, self-updating, and self-organizing representation of not only its environment, but also its own situation in the environment (self-representation). It must thus possess the capability to autonomously reflect on its primary mapping processes (representation of the environment) via a kind of meta-mapping aptitude, involving the consideration (awareness) of its own presence in the context of its surrounding world (Bateson 1972, Mahdavi 1998). Put simply, a cogitative system has a model of itself, a model of the environment, and a model of itself in the environment. Moreover, it can use the latter model to autonomously perform virtual experiments (i.e. consider the implications of its own interactions with a dynamically changing environment) and use the results of such virtual experiments to determine the course of its actions.

3 ELEMENTS

Following the above minimum definition of a cogitative building, a number of requirements emerge. Such a building must have a dynamic (real-time) and self-organizing (self-updating) representation that includes at least three kinds of entities associated with a building, namely:

i) Physical components and systems.
ii) Context (surroundings, micro-climate), and
iii) Internal processes (occupancy, indoor climate).

A simple way of thinking about this complex representation is to consider a virtual (digital) model of a building that "runs" parallel to the actual building. This model encompasses real-time information about the properties and states of salient building components and systems, about the immediate surrounding environment of the building, and about its internal processes.

4 APPLICATION

The presence of a comprehensive dynamic representation provides, as such, a number of benefits. It can act as an interface, allowing users to conveniently obtain information about their building and to communicate operational requests (i.e. desirable states of control devices and/or room conditions) to the building's environmental systems control unit. To the building managers and operators, it can provide, in addition, a reliable highly structured source of information toward supporting operational decision making in facility management, logistics, service, diagnostics, monitoring, and surveillance (Brunner & Mahdavi 2006).

However, these kinds of functionalities alone would not make a building cogitative. Rather, the critical faculty of a cogitative building is grounded in its autonomous use of the previously mentioned model toward auto-regulatory operations. A case in point is the operation of buildings' environmental systems for indoor climate control (heating, cooling, ventilation, lighting). A cogitative building can use a dynamically updated digital building representation toward implementation of a novel kind of model-based systems control technology that has been previously termed as simulation-based (or simulation-assisted), and proactive (Mahdavi 2001b, Mahdavi 2008, Mahdavi et al. 2005). The idea is that, in this case, a system bases its decisions regarding its future states on virtual experiments with its own digital representation. Thereby, the implication of alternative (candidate) future states of the systems are virtually tested and compared before one of them is realized. A simple instance of this approach may be summarized as follows:

At time t_i the actual state of the virtual model is used to create candidate options for the state of the building in a future time point t_{i+1}. These candidate options may include different positions of the buildings environmental systems and devices for heating, cooling, ventilation, and lighting controls. The options are then "virtually enacted" using predictive tools such as explicit numeric simulation algorithms or statistically based regression models and neural networks. Thereby, the computation of future system states makes use of the building model and the predicted boundary conditions (weather, occupancy) to derive the values of various building performance indicators (energy use, thermal and visual comfort) for a future time step t_{i+1}. The prediction results are subsequently compared and evaluated based on objective functions set by building users and operators. The option with the most desirable performance is selected and either realized by direct manipulation of the relevant control devices, or communicated as recommendation to the users and occupants.

5 TECHNOLOGY

Some features and ingredients of a cogitative buildings, as postulated in the previous sections, are already realized or under development. Others still await technical solutions feasible and scalable enough for wide use in practice. A number of related observations are given below, following the representational requirements of the three entity types discussed in section 3:

i) The long tradition in building product modeling research has resulted in detailed schemes and templates for the description of static building components and systems (IAI 2008, Mahdavi et al. 2002). Thereby, one of the main motivations has been to facilitate hi-fidelity information exchange between agents involved in the building delivery process (architects, engineers, construction specialists, manufacturers, facility managers, users). The representational stance of building product models is commonly static. In contrast, building control processes require representational systems that can capture procedural sequences of events, decisions, and actions. As opposed to abundant literature in building product modeling, there is a lack of an explicit ontology for the representation of building control processes. Specifically, there is still a lack of consistent representations that would unify building product, behavior, and control process information. However, progress in this area is occurring and existing problems are probably neither fundamental nor insurmountable (Mahdavi 2004b, Brunner & Mahdavi 2006).

ii) The sensory devices necessary for provision of information concerning external (e.g. weather) conditions represent fairly standard technology. Advances are required to broaden the range of monitored conditions (to cover, for example, sky dome's luminance distribution and cloud cover). Robust and low-cost designs would encourage a more pervasive application of such technologies (Mahdavi et al. 2006).

iii) The "sensory deprivation" of buildings has been recognized as a potential area of deficiency. New buildings are thus increasingly equipped with comprehensive sensory networks to monitor occupancy, indoor climate conditions, and, to a certain degree, states of technical devices for systems control. Main challenges in this area are twofold. On the one hand, further developments are needed to fulfill the aforementioned criteria of representational self-organization. This means that, in order to keep the digital model of the buildings′ physical constituents up to date, the sensory systems must detect and report changes in the location and position of building elements as well as interior objects (furniture, partition elements) and people (İçoğlu & Mahdavi 2005). On the other hand, the large amount of real-time monitored data must be structured and stored in an efficient and effective manner to support operational processes in building management domain.

A few recent efforts by the author's research team in the above mentioned technological development areas are briefly discussed in the next section.

6 RECENT ADVANCES

To address some of the research and development needs mentioned above, ongoing research addresses technological advances toward generating and maintaining self-updating building representations for cogitative buildings. Specifically, provision of updated information about external (sky) conditions, internal conditions (including people's presence and actions), and position of objects (interior elements) are discussed below.

6.1 *External environment*

Basic local meteorological data (air temperature and relative humidity, wind speed and direction, horizontal and vertical global irradiance and illuminance) can be dynamically monitored using standard sensing equipment. However, more detailed (high-resolution) monitoring of sky radiance and luminance distribution (including cloud distribution detection) still require complex and high-cost sensing technologies. Past research efforts (Roy et al. 1998, Mahdavi et al. 2006) have demonstrated that sky luminance mapping with digital photography can provide an alternative to high-end research-level sky scanners. This approach requires, however, calibration, as the camera is not a photometric device.

In a recent research effort (Mahdavi 2008), we further explored the use of a digital camera with a fish-eye converter toward provision of sky luminance maps of various real occurring skies (Figure 1). Toward this end, we developed an original calibration method that involves simultaneous generation of digital images of the sky hemisphere and measurement of global external horizontal illuminance. For each of the regularly taken sky dome images, the initial estimate of the illuminance resulting from all sky patches on a horizontal surface can be compared to the measured global illuminance. The digitally derived luminance values of the sky patches can be corrected to account for the difference between measured and digitally estimated horizontal illuminance levels. Thereby, the difference between measured and calculated global illuminance can be assigned to a sky area associated with the sun position (Mahdavi et al. 2006).

To empirically test the performance of calibrated digital sky luminance distribution mapping, we used a sky monitoring device equipped with twelve illuminance sensors that measure the horizontal illuminance resulting from twelve different sky sectors (Fig. 1).

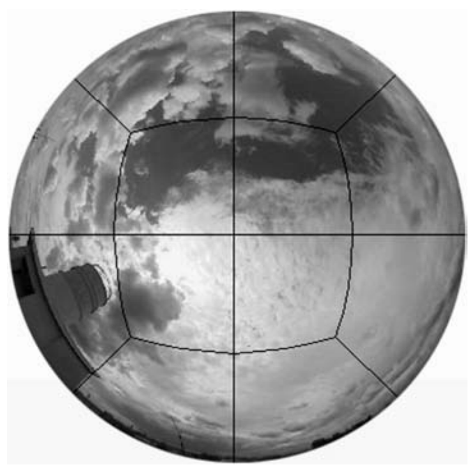

Figure 1. Fisheye digital image of sky dome (together with the projection of twelve sky sectors as "seen" by illuminance sensors).

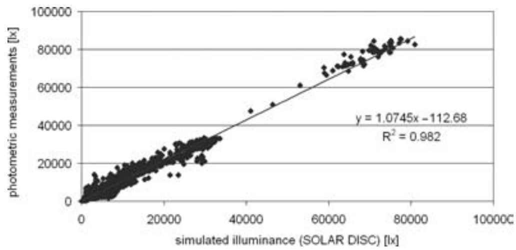

Figure 2. Comparison of measured external illuminance levels with corresponding camera-based values.

We then compared the illuminance predictions resulting from calibrated sky luminance maps to those resulting from respective photometric measurements. The results (Fig. 2) demonstrate that calibrated digital photography can provide a feasible technical solution toward provision of reliable high-resolution real-time sky maps (luminance distribution patterns) as part of the context model within the representational core of a cogitative building. Such context models can support, inter alia, the implementation of proactive control methods for the operation of buildings' lighting and shading systems.

6.2 *Dynamics of spatial models*

To generate and maintain a self-updating model of the physical elements of a spatial unit in a building (e.g. the enclosure elements of and furniture elements in a room) is not a trivial task. Various location sensing technologies and methods have been proposed to autonomously track changes in the location of objects and artifacts in facilities. Such information could be used to continuously update product models of facilities. In previous research (İçoğlu & Mahdavi 2007), we first experimented with network cameras (some equipped with pan-tilt units to broaden the coverage area). Thereby, the location-sensing functionality was based on recognition of visual markers (tags) attached to objects (walls and windows, furniture elements, etc.).

To test the system, we selected a typical office environment (Fig. 3) that involved 25 objects relevant for the demonstrative operational application (lighting control system). For each object, a tag was generated. Consequently, the tags were printed and attached on the corresponding objects. The implemented location sensing system achieved in our test a 100% identification performance, extracting all tag codes and recognizing all objects. A graphical representation of the test-bed, as generated and displayed by the system, is illustrated in Figure 4. The object location results can be seen together with the sensed occupancies.

To evaluate the accuracy of location results, "position error" is defined as the distance between the ground-truth position (actual position information) and the sensed position of the tag. "Orientation error" is defined as the angle between the tag's true surface normal and the sensed surface normal. Generally, the test implied for the system an average position error of 0.18 m and an orientation error of 4.2 degrees on aggregate. The position error percentage had a mean value of 7.3% (İçoğlu & Mahdavi 2005).

The above implementation was, as mentioned before, based on network cameras. To achieve the required level of scene coverage, most of such cameras in a facility need to be augmented with pan-tilt units. To explore an alternative that would not involve moving parts yet would offer wide scene coverage, we have also considered the potential of digital cameras with fisheye lenses as the primary visual sensing device

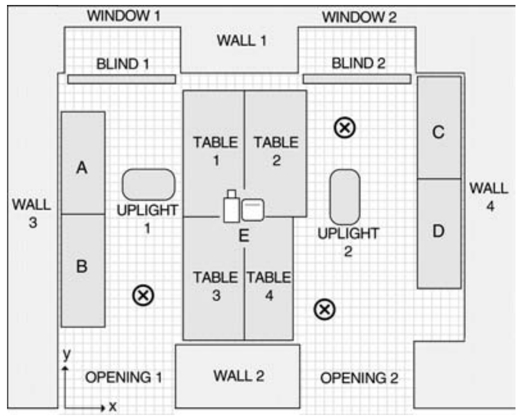

Figure 3. Plan of the test-bed ("A" to "D" refer to Cabinets; "E" refers to Camera.

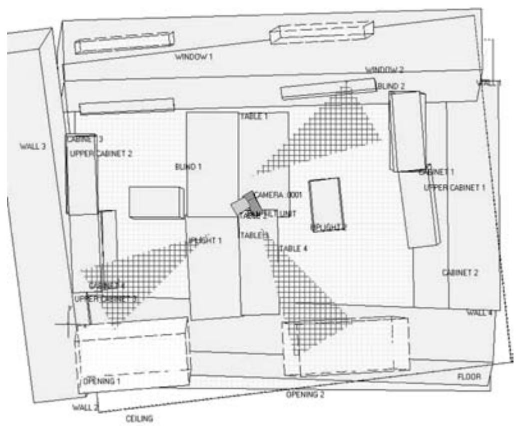

Figure 4. Graphical representation of the test-bed generated by the user interface server. The objects are drawn with the extracted locations.

Figure 5. Sample fisheye image of the test space.

Figure 6. Examples of image segments extracted from the fisheye picture using equi-rectangular transformation.

(Mahdavi et al. 2007). Toward this end, we have performed an initial test, whereby, other than the cameras, all other components of the previous implementation (tags, detection algorithms, test space) are unchanged.

The test involved the following steps: *i*)we equipped an ordinary digital camera with a fisheye lens; *ii)* we mounted this camera in the center of the test space. Altogether 17 tags were used to mark various room surfaces and furniture elements; *iii)* four fisheye images of the test space were generated by the camera from four different vantage points close to the center of the room (see Figure 5 as an example); *iv)* these four images were dissected into nine partially overlapping segments (see, for example, Figure 6); *v*) the resulting image segments were analyzed using the previously mentioned image processing method (İçoğlu & Mahdavi 2007).

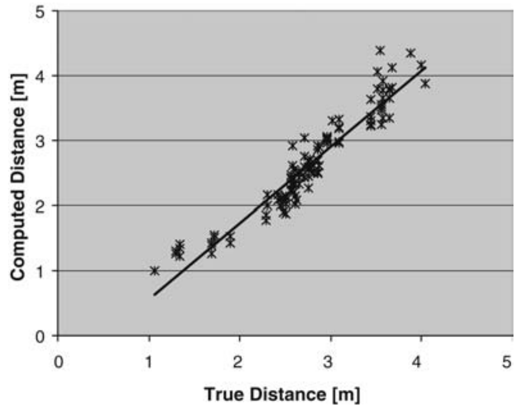

Figure 7. Actual versus computed tag-camera distances.

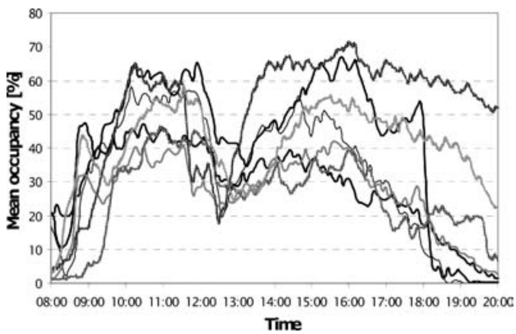

Figure 8. Observed occupancy levels in 7 different offices in an office building for a reference day.

Figure 7 shows the relationship between the actual and computed tag-camera distances. This initial test resulted in a rather modest tag detection performance (67%) and distance estimation accuracy ($6 \pm 10\%$). However, further calibration of the camera and assorted software improvements are likely to improve the performance of the system in the near future.

6.3 *People and their actions*

People's presence and their interactions with the buildings' environmental systems (for heating, cooling, ventilation, lighting) have a major effect on buildings' performance (Mahdavi 2007). Such interactions are near-impossible to accurately predict at the level of an individual person. For example, Figure 8 shows the considerable diversity of the observed mean occupancy (in percentage of the working hours) over the course of a reference day (representing observations over a period of 12 months) in seven staff offices in a building in Vienna, Austria.

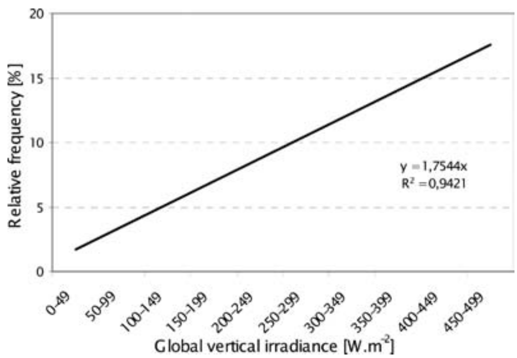

Figure 9. Illustrative simulation input data model for normalized relative frequency of occupant-based closing shades actions as a function of the global vertical irradiance (based on data collected in two office buildings).

However, general control-related behavioral trends and patterns for groups of building occupants can be extracted from long-term observational data. Moreover, as our recent research in various office buildings in Austria has demonstrated, such patterns show in many instances significant relationships to measureable indoor and outdoor environmental parameters (Mahdavi 2007). For example, Figure 9 illustrates a model (derived based on data collected in two office buildings) for the prediction of the occupants' use of window shades (expressed in terms of the normalized relative frequency of occupant-based closing shades actions) as a function of the incident global vertical irradiance on the respective building facades.

The compound results of these case studies are expected to lead to the development of robust occupant behavior models that can improve the reliability of building performance simulation applications and enrich the control logic in building automation systems (particularly those pertaining to simulation-based building systems control methods).

7 AN ILLUSTRATIVE IMPLEMENTATION

As noted earlier (section 2), a cogitative system can use its internal representational system to autonomously and preemptively examine the implications of its own interactions with a dynamically changing environment and use the results of such virtual experiments to determine the course of its actions. The generic process toward the utilization of this faculty toward environmental systems control in buildings was discussed in section 4. In our past research, we have applied this process, amongst others, in lighting and shading systems control domain (Mahdavi 2008, Mahdavi et al. 2005). A recent implementation involved a test bed (Figure 10) in the building physics laboratory

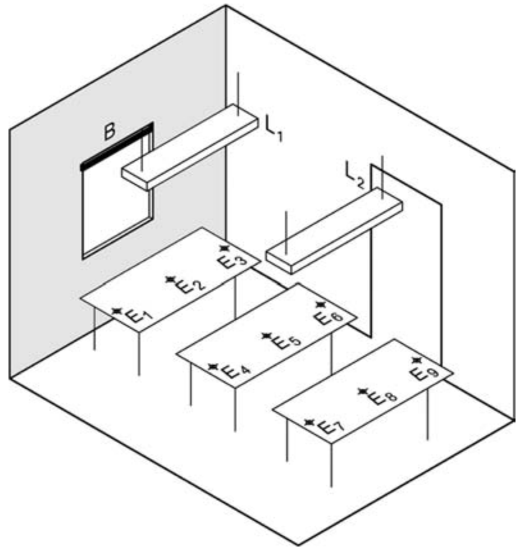

Figure 10. Schematic illustration of the test bed with the two luminaires (L_1, L_2), the shading device (B), and the workstation with reference points (E_1, E_2, E_3) for workstation illuminance.

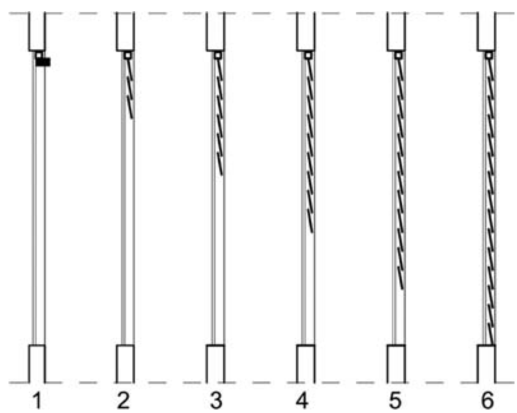

Figure 11. Illustration of the six discrete control states of the shading device in the test bed.

of our Department. The objective was, in this case, to implement and test a simulation-based lighting and shading control strategy. Relevant control devices are two suspended dimmable luminaires and a window shading system (Figure 11). Daylight is emulated via a special flat luminaire (STRATO 2008) placed outside the window of the test room. The luminous flux of this source is controlled dynamically according to available external global illuminance measured via a weather station installed on top of a close-by

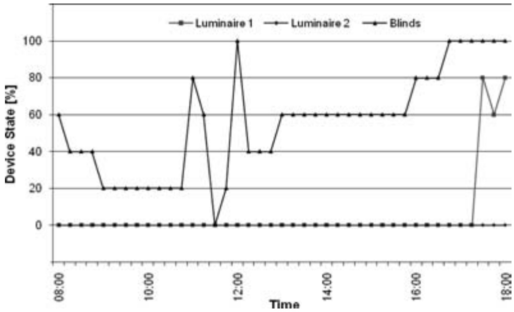

Figure 12. Recommendations (desirable states of lighting and shading devices) of the simulation-assisted lighting and shading control system for a reference day.

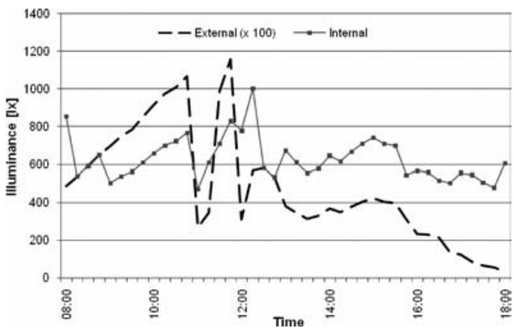

Figure 13. Predicted values of the relevant control parameter (workstation illuminance level) together with the prevailing external global illuminance.

university building. The simulation-assisted control method operates as follows:

At time t_i, the actual state of the virtual model is used to create candidate options for the state of the building in a future time point t_{i+1}. These options include six different positions of shading device and six discrete dimming positions for each of the two luminaires. The options are then simulated using the lighting simulation application RADIANCE (Ward Larson & Shakespeare 2003). Thus, values of various building performance indicators (e.g. horizontal illuminance at multiple locations in the space, illuminance distribution uniformity, different glare indicators, electrical energy use for lighting) are computed for a future time step t_{i+1}. The prediction results are subsequently compared and evaluated based on objective functions set by building users and operators.

To illustrate the control functionality and performance of this approach, Figure 12 shows the recommendations of the system (the dimming position of the two luminaires and the deployment position of the shading device) over the course of a reference day (office working hours). Figure 13 shows the corresponding values of the external global illuminance and

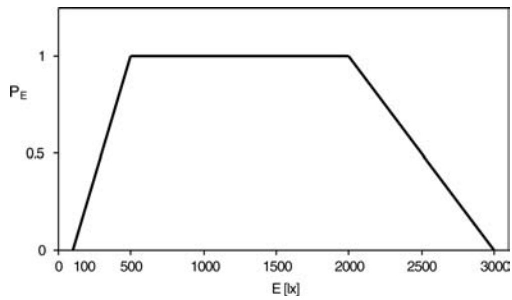

Figure 14. Illustration of the assumed preference function for workstation illuminance.

the values of the relevant control parameter (i.e., mean workstation illuminance level, derived as the arithmetic average of the illuminance at points E_1, E_2, and E_3 as shown in Figure 10).

For the above experiment, the objective function required the optimization of workstation illuminance level (see Figure 14 for the corresponding preference function), while minimizing electrical energy consumption for lighting. Parallel measurements of the maintained illuminance levels throughout the test period showed a very good agreement with the predicted results, confirming once more the potential of the proposed methodology as a promising contributor to a cogitative building's self-regulatory control functionality.

8 REFLECTIONS

Buildings are subject to complex and dynamic changes of different kinds and cycles. Environmental conditions around building as well as organizational needs and indoor-environmental requirements of building occupants change continuously. Increasingly, buildings include more flexible, moveable, and reconfigurable components in their structures, enclosures, and systems. Moreover, building parts and components age over time, and are thus modified or replaced repeatedly. Likewise, buildings are frequently overhauled and adapted in view of new services and functions (Mahdavi 2005). Under these dynamically changing conditions, provision of functionally, environmentally, and economically desirable services represent a formidable planning, control and management challenge. The proactive and auto-regulatory control faculties of cogitative buildings have the potential to effectively address certain aspects of this challenge. These faculties can result from a creative synthesis of advanced information modeling techniques (involving both building products and processes), pervasive environmental monitoring and location sensing features, and simulation-based feed forward control logic.

Given the recent advances in these areas, the fulfillment of the technological prerequisites for the emergence of cogitative buildings is a realistic proposition.

Nonetheless, cogitative buildings, both as vision and as program, cannot be exempted from a multifaceted critical discourse that is not limited to technical matters. Such discourse cannot be comprehensively addressed in the present – primarily technical – contribution, but at least two common concerns should be briefly mentioned.

A recurrent objection to the cogitative buildings vision maintains that intensive technology application cannot replace careful and effective building design. An overdependence on technology makes buildings in fact not only complex and susceptible to failures and breakdowns, but also energetically inefficient. This possibility is not to be rejected offhand, but it would not be a proper instance of implementing truly cogitative building technologies: Application of "soft technologies" (sensor networks, software) can, in fact, reduce the overt dependence on resource-intensive hardware (e.g. for environmental controls). Note that biological intelligent and cogitative systems are not energetically inefficient. Given the complex occupational, technical, and organizational requirement profile of contemporary buildings, utilization of passive environmental control methods would be unrealistic, unless, as the cogitative buildings vision suggests, advanced sensory and computational tools and methods are applied.

A second common criticism concerns the notion of an all pervasive dynamic self-updating building model that continuously monitors occupants' presence and actions. This is, for some, reminiscent of circumstances in an Orwellian "surveillance state" and could pose, as such, a threat to occupants' privacy and integrity. Moreover, the occupants of buildings that "have their own mind" may become entirely dependent on (and patronized by) a complicated and opaque control hierarchy. These concerns must be taken seriously. As with many other technological advances (e.g. internet, mobile telephony), the threat of data misuse is present and must be understood and effectively addressed. Cogitative building technologies should act – and be seen as – efficient and enabling. Incorporation of sentience in building operation should empower, not patronize inhabitants. Occupants of a cogitative building should find an efficiently operating indoor-environmental context that is accommodating of their individual preferences and requirements.

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Model-based management tools and systems

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Erection of in-situ cast concrete frameworks – model development and simulation of construction activities

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ABSTRACT: The erection process of in-situ cast concrete frameworks in multi-storey housing involves a wide range of non-value adding activities, resulting in poor process efficiency. This paper describes the process and presents a model for discrete-event simulation of activities and resource use involved in the construction of in-situ cast concrete frameworks. The model simulates the work flow which is subjected to multiple work locations and resource availability constraints. The model functionality and simulation approach together with validation and verification of the model are described. It is shown that the model can reproduce the dynamic behaviour in a work flow constrained by resource availability. The model enables exploration of new ways to improve the construction process efficiency by reducing waste and better use of resources.

1 INTRODUCTION

An established and commonly used method for construction of the structural frame in multi-storey housing is the use of concrete in combination with temporary or permanent formwork systems. The construction method consists of several on site activities carried out sequentially or in parallel where materials, equipment and workers are interacting in a complex way, influencing the total work flow. Poor planning and control are important reasons for process variability, low resource utilization and a high level of non-value adding activities (waste). Studies have shown that the cost of waste in construction projects represents 30–50% of the total production cost (Josephson and Saukkoriipi 2005). Established organizational structures and traditional contractual and union-related agreements also contribute to waste creation. Planning of construction work is often influenced by traditional way of thinking and practice using empirical data for estimation of project duration. Little or no effort is actually spent on critically review the way the work is organized and how the resources are used. Exploration of the full potential of the construction process requires an approach which is not restricted by existing process obstacles and current practice.

Discrete-event simulation is a widely accepted research method for studying complex processes. The technique enables consideration of randomness in activity duration and the influence of resource availability as a constraint to construction work flow.

The technique has been used within construction related research for many years. Earth moving operations were one of the first main applications where simulation was used and further developed (Halpin 1977, Hajjar & AbouRizk 1994, Smith et al. 1995). The ready-mix concrete process is another area where the technique has been widely applied (Zayed & Halpin 2000, Sobotka et al. 2002, Wang & Halpin 2004). These models focused on optimization of resources or the order handling process. In (Huang et al. 2004) different form reuse schemes for gang forming systems in the construction of high-rise buildings were explored using a simulation-based approach. Other areas of interest are development of algorithms for optimization of stockyard layout (Marasini & Dawood 2002), consideration of breaks (Zhang & Tam 2005) and overtime (Yan & Lai 2006) in production and dispatching of ready-mix concrete. Discrete event simulation has also been used for analyzing and highlight benefits of introducing different Lean-concepts into existing construction processes (Tommelein 1997, Halpin & Keuckmann 2002, Alves et al. 2006, Srisuwanrat & Ioannou 2007).

The main focus in previous research has tended to be on solving specific issues in a particular part of the process. However, in order to describe the on-site work flow, a broader approach is necessary where all activities and resources involved in the construction process are considered. The interplay between multiple activities carried out at different work locations sharing the same resources must be considered in order to describe the dynamic behaviour of the total work flow. Use of discrete-event simulation to study multiple work flows in a concrete framework erection influenced by resource constraints has not been fully addressed in previous research.

This paper presents a model for discrete-event simulation of activities and resources involved in the construction process of in-situ cast concrete frameworks in multi-storey housing. The model simulates work flows carried out at multiple work locations constrained by resource availability. This approach could give new insights how to plan and organize construction work and resources in order to improve process efficiency and reduce waste.

2 MODEL DEVELOPMENT

2.1 *Case-studies*

Four projects (A-D) were studied in order to obtain necessary insights into current practices in the construction of in-situ cast concrete frameworks. The data were collected by on-site observations and by interviewing responsible site mangers and supervisors. In addition, the site visits also involved documentation of resource usage practice, construction methods used and activity durations. The knowledge obtained was used to develop a conceptual model of the construction process. It also gave insights into requirements for implementation of the conceptual model in simulation software. To obtain real process data, detailed measurements of on site activities were carried out in projects C and D (Lundström & Runquist 2008, Lindén & Wahlström 2008). Because of the amount of available real process data for project D, this project was selected for an extended validation and verification of the simulation model. This is further described in chapter 3.

The construction process of the concrete framework was found to be similar for all studied projects. The process starts with wall operations consisting of the following steps:

- Erection of temporary wall formwork,
- Placement of reinforcement and electric cables,
- Erection of second-side of wall formwork
- Pouring of concrete into the formwork,
- Stripping of the formwork the next day.

When all walls belonging to the same slab pour unit have been poured, the formwork is moved to the next slab pour unit. At the same time the slab operation activities start consisting of the following steps:

- Erection of props and stringer for the slab formwork system and balcony slabs,
- Placement of permanent formwork system (lattice girder elements),
- Sealing of formwork and placement of reinforcement over joints and complementary bottom reinforcement,
- Install prefabricated elements such as balconies, stairs and columns,
- Placement of building services which are embedded into the concrete slab,
- Placement of top reinforcement and finalize formwork sealing,
- Placement of concrete and surface treatment,
- Props removal and re-shoring
- The process is then repeated for the next floor by starting with the erection of wall formwork.

2.2 *Development of conceptual model*

Next a model was developed to describe the logical dependencies of activity work flow and the use of resources in the construction processes observed, figure 1. An activity was defined as one or more work operations carried out over a continuous and clearly defined period of time using the same setup of resources. The model covers a complete set of activities (numbered 1-23) connected to a work location which represents a slab section (pour unit). Each slab section could consist of several wall units (wall cycles). Activities 1 to 7 represent one single wall cycle. The process starts with erection of the first side of the wall formwork (activity 1). All wall units belonging to the same slab section are processed during activities 1–7 until all walls have been poured. When activity 7 is finished and all wall units have been poured, the process continues with the erection of props and stringers (activity 9) and the temporary formwork is at the same time moved to the next work location (activity 8). The simulation stops when activity 23 is finished at the top floor. If the floor slab is divided into several sections (work locations), each section is described according to the process scheme in figure 1. There exists only one resource pool for each resource type controlling the transactions of resources between the different work locations. This approach could also be used to model projects consisting of several buildings which are erected simultaneously sharing the same resources.

2.3 *Description of the simulation software*

The conceptual model was implemented in the commercial simulation software Extend^{TM}, which is general-purpose software for continuous and discrete-event simulation. Extend^{TM} uses a graphical user interface which facilitates understanding and communication.

A model is created by selecting blocks which are added to the model window and then connected. The connected blocks represent the system of interest. Extend^{TM} provides many types of blocks which all are pre-programmed to perform a specific task. A detailed description of how the software works are given

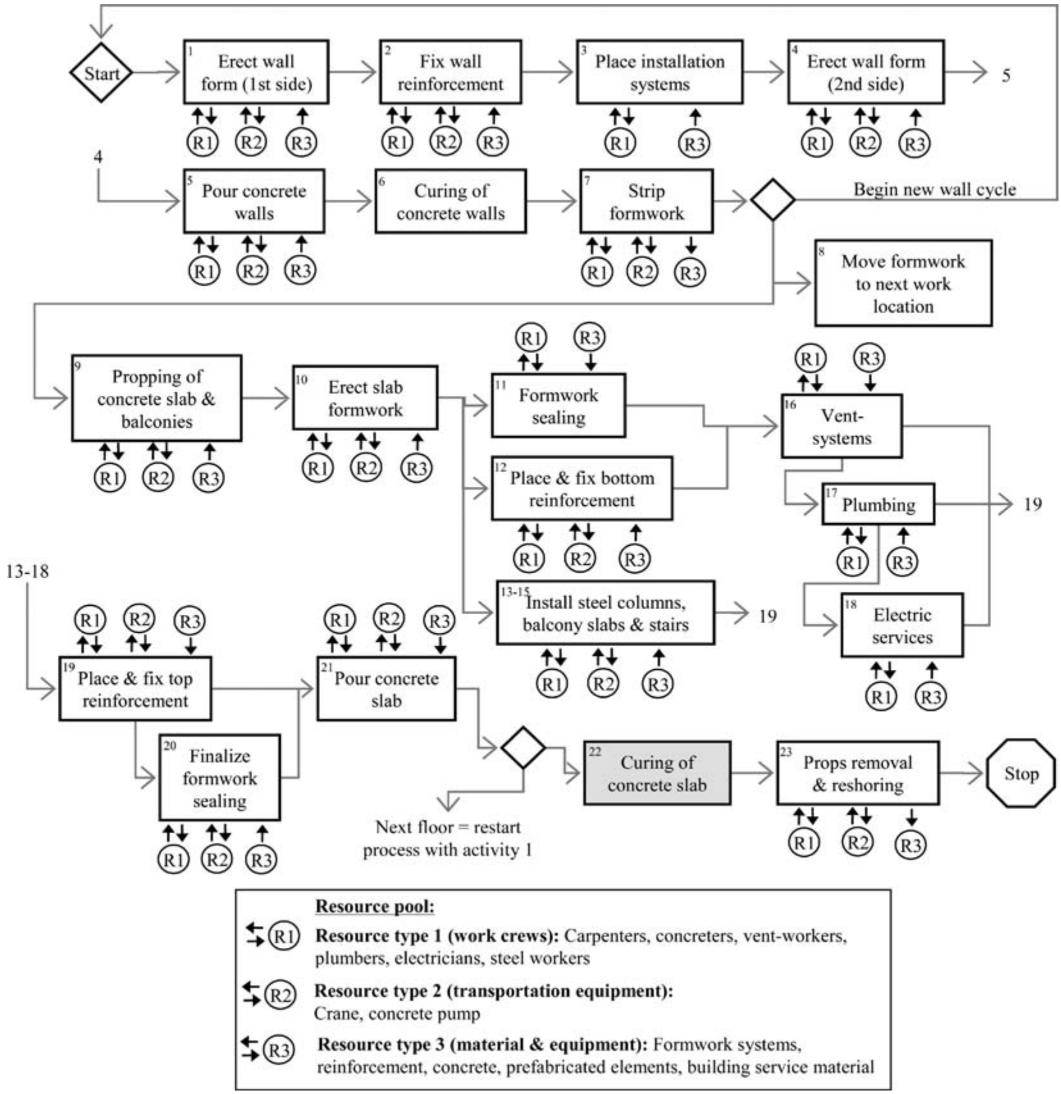

Figure 1. Conceptual model of activities and resource use involved in the erection process of in-situ concrete frameworks.

in (Krahl 2002, Redman & Law 2002, Schriber & Brunner 2004).

Extend^{TM} uses an event scheduling approach which is somewhat different from the established systems used for simulation of construction processes, such as CYCLONE (Halpin 1977) and STROBOSCOPE (Martinez 1996). These systems are based on a modified activity scanning strategy which is more suitable for model work flows in cyclic form (Lu & Wong 2007). However, since the research focused on studying the overall erection process of the concrete framework which could be seen as being processed by a sequence of activities performed in a linear work flow repeated at different work locations and constrained by resource avail ability, the event scheduling strategy was considered to be applicable.

2.4 *Implementation in simulation software*

The conceptual model described in previous section was implemented in the Extend^{TM} software system to simulate the work flow and the use of resources as illustrated in figure 2. An item arrives at event time T_1 initiating activity 1 and is viewed as a "work order" flowing through the system initiating activities.

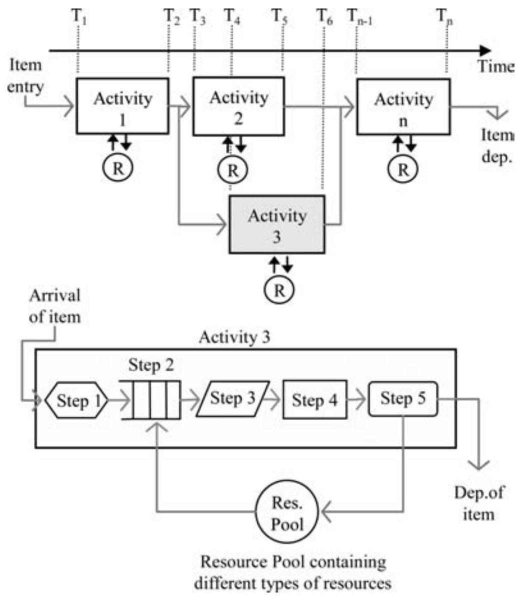

Figure 2. Modeling approach used to describe activity sequencing and use of resources.

During the simulation run, events changing the state of the system are scheduled. Events represent, for instance, start and finish time of activities 1 to n ($T_1 - T_n$) as illustrated in figure 2.

The lower part of figure 2 illustrates how all activities are modelled using existing pre-programmed blocks, all arranged in similar way. Simulation of each activity consists of five steps:

1 *Preparation:* The item arrives and is assigned a priority describing the importance of the activity when requesting resources. It is also possible to define a delayed start for the activity. For instance, activity 3 is scheduled to start with a delay in relation to activity 2 ($T_4>T_3$), as illustrated in figure 2.
2 *Allocation of resources:* The item enters a multi-resource queue where a request to allocate a specific quantity of different resources is sent to the global resource pool. Several types of resources could be specified in the request, such as carpenters, concreters, crane, materials etc. If the requested quantity of the different resources types is available at the specified time, these are allocated to the multi-resource queue, enabling the item to continue. If the resources in the resource pool are busy, supporting other activities, the item has to wait until the resources requested become available. If several activities request the same type of resources simultaneously, the activity with the highest priority will receive the requested resources first.
3 *Calculation of serving time:* In this step, the activity duration is calculated based on actual quantity of work, production rate and number of resources allocated in step 2.
4 *Processing of activities:* The item is held while being processed according to the calculated time in step 3.
5 *Release of resources:* The allocated resources are released and sent back to the resource pool where they then become available for use in other activities. Resources such as materials are permanently consumed by the activity and not released back to the resource pool.

When step 5 has been completed, the activity is finished and the item is routed to initialize the following activities defined by the model order. The time it takes for the item to be processed by steps 1 to 5 is recorded by the simulation clock which is used to calculate total time and the resource utilization factor.

Several blocks describing the logic of work flow between different work locations have been added to the model in order to enable simulation of a complete erection process of one or more multi-storey frameworks.

2.5 *Description of required input*

Two types of input are necessary to run a simulation: general information and activity-specific information. The general information consists of:

- Number of floors and wall units per floor or slab section
- Number of available resources (work crews, temporary formwork systems, cranes)
- Work-hours' schedules subjected to each work crew
- Curing time before stripping of the temporary formwork or removal of propping and re-shoring
- Cost per resource which could be defined as cost per time unit or per unit used.

The activity specific information needed is:

- Quantity of work defined as unit per activity, for instance m^3 concrete poured or m^2 erected formwork
- Number and type of resources needed per activity
- Production rate defined as man-hours per unit. The production rate can be either a constant value or variable according to a specific statistical distribution.

3 MODEL VERIFICATION AND VALIDATION

3.1 *Description of model data used*

The project chosen for an extended validation and verification of the simulation model consists of two,

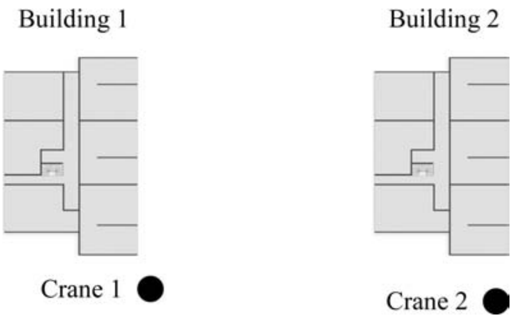

Figure 3. Illustration of layout of the two buildings and crane location.

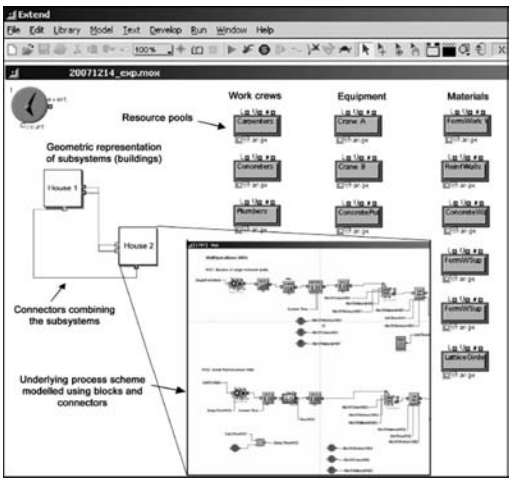

Figure 4. Simulation model in Extend^{TM}.

six-storey buildings which were erected alternately supported by two tower cranes. The building layout and the construction method used were identical for the two buildings. The construction process of the in-situ concrete framework in the two buildings corresponds to the process scheme described in figure 1. In figure 3 the placement of the two buildings and the cranes are illustrated.

Figure 4 shows the simulation model implemented in Extend^{TM}. The construction process of each building is described by the process scheme given in figure 1. The two process schemes are connected to each other which means that the current state of the erection process in one of the building influences the other building and vice versa. The different resources are modeled as unique blocks supporting the modeled activities in both of the buildings.

The data needed for running the simulation model are given in tables 1–3. In table 1 general information about the project are given while activity specific information are given in table 2 and 3 respectively. All data have been obtained from interviews, construction documents, and on-site measurements of activity durations. The production rate (P-rate) values given in table 3 are based on on-site measurements of activities'

Table 1. General information inserted into the simulation model.

General information:	
Number of floors	6
Number of slab sections per floor	1
Number of wall units per floor	6
TCPS* Walls (hours)	15
TCPS Slab (hours)	720
Work-hour schedule	7–12 a.m. 13–16 p.m.
Number of carpenters available	6
Number of concreters available	4
Number of electricians available	2
Number of steel-workers available	2
Number of vent-workers available	1
Number of plumbers available	2
Number of cranes available	2
Number of concrete pumps	1
Total amount of wall formwork (m^2)	180
Total labour cost (EUR/hour)	480
Total crane cost (EUR/hour)	133

* Time between Concrete Placement and Striking of formwork

Table 2. Work-load defined by each activity subjected to one pour unit of slab.

	Work-load defined per activity	
Activity	Unit	Quantity
1. Erect wall formwork	m^2 formwork	57
2. Wall reinforcement	kg rebar	477
3. Electric system	metre elec.pipe	53
4. Erect wall formwork	m^2 formwork	57
5. Pour concrete	m^3 concrete	10
7. Strip formwork	m^2 formwork	114
8. Move formwork	m^2 formwork	114
9. Props & stringers	m^2 supported	515
10. Lattice girder elem.	m^2 elements	463
11. Sealing of elments	m^2 sealed area	463
12. Bottom rebars	kg rebar	385
13. Steel columns	no columns	4
14. Install balconies	m^2 balcony slab	52
15. Install stairs	no stairs	1
16. Vent-system	metre of ducts	13
17. Plumbing	metre of pipes	462
18. Electric system	metre of el.pipes	225
19. Top rebars	kg rebar	1900
20. Stop ends	metre of sealing	99
21. Pour concrete	m^3 concrete	116
23. Props removal	m^2 popped area	515

Table 3. Resource allocation strategy, material cost data and production rates defined by each activity subjected to one pour unit of slab.

Activity	Resource Type*	Material cost EUR/unit	P-rate hours/unit
1. Erect wall form	2A + 1G	1.6	0.17
2. Rebar walls	1B + 1G**	1.0	0.01
3. Electric system	1C	0.5	0.03
4. Erect wall form	2A + 1G	1.6	0.11
5. Pour concrete	1B + 1G	103	0.19
7. Strip formwork	2A + 1G	n/a	***
8. Move formwork	2A + 1G	n/a	0.07
9. Props & stringers	2A + 1G**	2.8	0.05
10. Lattice girders	2B + 1G	24.0	0.02
11. Sealing elements	2B	0.9	0.02
12. Bottom rebars	2B + 1G**	0.7	0.05
13. Steel columns	2D + 1G	330	2.0
14. Install balconies	2B + 1G	166	0.11
15. Install stairs	2B + 1G	5106	2.0
16. Vent-system	1E	7.0	0.15
17. Plumbing	2F	6.2	0.14
18. Electric system	1C	1.2	0.02
19. Top rebars	2B + 1G**	0.7	0.02
20. Stop ends	1A + 1G**	2.9**	0.14
21. Pour concrete	3B + 1H	123	0.2
23. Props removal	2A + 1G**	n/a	0.03

* A = Carpenter, B = Concreter, C = Electrician, D = Subcontractor (steel), E=Vent worker, F = Plumber, G = Crane, H = Concrete pump
** Crane used only for lifting material to/from work location
*** Included in activity 1

durations together with quantity of work carried out by each activity.

3.2 *Description of methods used for validation and verification*

To ensure the validity of a simulation model its behaviour must be in line or comparable with the actual performance of the process in the real world. In (Shi 2002) three methods for validation and verification of simulation models are presented. Inspired by these ideas the following three methods have been applied for validation and verification of the present model;

- Method 1 "Chronological order of activity executions": This method consists of two tests. The first is a logical test to ensure that activities are executed as expected and the second is a time test where simulated start time of each activity is compared to corresponding start time obtained from on-site measurements. The tests are carried out in two steps. The first step focus on a detailed but limited part of the process such as the activities involved in one wall cycle or activities involved in the construction of one floor slab. The second step focus on the overall work flow subjected to all floors in both of the buildings. The interesting aspects of these two tests are to ensure the correlation between simulated and actual start time values both at a single activity level and at an overall floor cycle level.
- Method 2 "Operating counts": The method aims to ensure that a wall activity or a slab activity are executed the correct number of times. Usually, the method also includes control of activity duration. However, since all values inserted into the model are based on real process data and are deterministic, the idea of controlling duration at activity level is not of interest for validation purpose in this case.
- Method 3 "Activity cycles of resource entities": An important aspect of the method is the transaction between the different resource pools and each activity. An important test is therefore to ensure that the resources involved in an activity are allocated and released as expected. This test is carried out by studying resource trace-reports. Available data of actual crane utilization obtained from on-site measurements are also used for verification of the simulated crane utilization factor.

Table 4. Simulated and measured start time for activities 1-7 in the first wall cycle at floor 1 in building 1.

Act no:	Duration Hours	Simulated Start time	Measured Start time
1	5.0	7	7
2	6.0	7.8	8
3	1.5	10.3	10
4	3.0	11.8	12.5
5	2.0	13.8	14.2
6	15.0	16	16
7	*	31	31

* Cycle repeated the next day with stripping wall formwork. Duration time is included in activity 1.

3.3 *Method 1: Chronological order of activity executions*

In table 4 simulated and measured start time values for wall activities are given. The values represent activities 1–7 (according to fig. 1) involved in the first of six wall cycles at floor number 1 in building 1. All start time values are given in hours. The simulation run starts at simulated time = 0. Activity 1 which represents erection of the first side of the wall formwork has a start time = 7 hours or 7 a.m. the first day. Striking of wall formwork (activity 7) starts after 31 simulated hours which corresponds to 7 a.m. the second day. The deviation between simulated and measured start time for activity 4 was due to a lunch break. In the simulation, the activity starts directly before lunch break but in reality the activity starts directly after the lunch break.

Table 5. Simulated start and finish time for slab activities 9-21 for the first floor in building 1.

	Duration	Start time Simulated	Measured	Diff [%]
Act no 9	8*	153	151*	+1.0
Act no 10	4	177	175	+1.0
Act no 11	4	182	181	+0.5
Act no 12	8	201	199	+0.1
Act no 13	4*	201	199*	+0.1
Act no 14	3*	206	199*	+3.5
Act no 15	1*	224	223*	±0.0
Act no 16	2	204	199	+2.5
Act no 17	21	204	200	+2.0
Act no 18	13.5	207	200	+3.5
Act no 19	20	207	203	+1.9
Act no 20	12	249	250	±0.0
Act no 21	8*	296	295*	±0.0

* Based on interviews of responsible site manager.

It is concluded that simulated and measured start times are correlated. The simulated order of activity executions also corresponds to what was observed in reality.

In table 5 simulated and measured start time of activities 9-21 (numbers according to fig. 1) for the first floor in building 1 are given. The start time values are given in hours. The slab operation process starts with erection of props and stringers (activity 9 in fig. 1) at simulated time = 153 hours or 9 a.m. day 7. Measurements are missing for some activities and their start time and duration were confirmed by responsible site manager. The difference between simulated and measured start time is in the range of 0–3.5%. It is thus concluded that the simulated activities are well correlated with the actual progress of slab activities.

The next step in the validation process was to study the overall work flow subjected to each floor and the interaction between the two buildings. For this purpose the availability of measured data was limited and the verification of simulated values were carried out by interviewing the responsible site manager.

In table 6 simulated start and finish times of the first and last wall cycle at each floor in building 1 and 2, are presented.

The simulated start time values were used to ensure the overall work flow order. The expected work flow should start at floor number 1 in building 1. When the sixth wall cycle has been completed, the formwork is removed to building 2 which triggers the wall activities to start at floor number 1 in building 2. This procedure is then repeated in the opposite direction as the two buildings are alternatively erected.

As shown in table 6, the simulated start and finish time values correlate well with the expected work flow occurring in reality.

Table 6. Simulated start and finish time for the first wall activity in the first cycle and the last activity in the sixth cycle at each floor and building.

	Building 1		Building 2	
	Start* Time	Finish* Time	Start* Time	Finish* Time
Floor no 1	7	151	153	319
Floor no 2	321	487	489	655
Floor no 3	657	823	825	991
Floor no 4	993	1159	1161	1327
Floor no 5	1329	1495	1497	1663
Floor no 6	1665	1831	1833	1999

* Values given in hours.

Table 7. Simulated start and finish time for slab activities 9-21 at each floor and building.

	Building 1		Building 2	
	Start* Time	Finish* Time	Start* Time	Finish* Time
Floor no 1	153	319	321	488
Floor no 2	489	655	657	824
Floor no 3	825	991	993	1160
Floor no 4	1161	1327	1329	1496
Floor no 5	1497	1663	1665	1832
Floor no 6	1833	1999	2001	2152

* Values given in hours.

In table 7 the simulated start time of activity 9 and finish time of activity 21 for each floor and building are shown. All values are given in hours. The lead time of slab operations for each floor is thus given by subtracting finish time from start time. The simulated lead time for building 1 and 2 is 6.9 days (mean value).

The simulated floor cycle is calculated by subtracting start time for one floor from the start time value for the floor located immediately below the first one. For example, the cycle time between floor 2 and 3 in building 1 is 336 hours (825-489) or 14 days. The simulated floor cycle time of building 1 and 2 is constant at 14 days indicating that the model shows on a steady behaviour which is reasonable because all input values are deterministic and no disturbances are simulated.

The lead time for activities 9–21 was measured to 7 days for the first floor in building 1. The other floors were expected to have the same lead time according to the site manager. The expected floor cycle time was 14 days and measurements of the first floor cycle confirmed that. The floor cycle consisted of six days of wall operations and one additional day for moving wall formwork system between the two buildings. The

Table 8. Number of simulated activity iterations.

	Building 1	Building 2
Activities 1-7	36	36
Activity 8	6	6
Activities 9-21	6	6

Table 9. Carpenters progress report.

SimTime (hours)	Event description	Available in Res. pool
7.0	Allocate 2 carpenters to act 1	0
11.8	Release 2 carpenters from act 1	2
11.8	Allocate 2 carpenters to act 4	0
14.8	Release 2 carpenters from act 4	2
31.0	Allocate 2 carpenters to act 1	0
35.9	Release 2 carpenters from act 1	2
37.0	Allocate 2 carpenters to act 4	0
38.8	Release 2 carpenters from act 4	2

remaining seven days were used for construction of the floor slab.

Given information about actual resource usage, quantity of work and productivity rates, it is concluded that the model is capable of reproducing expected output such as lead times and floor cycle times.

3.4 *Method 2: Operating counts*

Table 8 shows the simulated number of iterations for activities 1–7, activity 8 and activities 9–21 respectively. Activities 1–7 representing wall operations, are repeated 36 times which corresponds to six iterations at each floor. Activity 8 representing the movement of wall formwork between the two buildings is repeated 6 times in one direction and 6 times in the reversed direction. Activities 9–21 are repeated only one time at each floor which gives a total of six iterations for one building. The test confirms that the operating counts were correlated with the actual number of counts for each activity.

3.5 *Method 3: Activity cycles of resource entities*

In table 9 the transactions of carpenters involved in the wall formwork cycles are shown. The simulated time is given in hours and the events describe the transactions between the carpenters resource pool and the wall formwork activities 1 and 4 according to figure 1. The listed events cover the first two simulated days.

The simulated and measured crane utilization factors are given in table 10. The utilization factor is defined as the time the crane is in use in relation to the total time the crane is available.

Table 10. Crane utilization factor.

	Simulated [%]	Measured [%]
Crane 1	30	25
Crane 2	22	n/a*

* Measurement data only available for crane 1.

The utilization factor in table 10 refers only to the time the crane was used in activities 1-21. The simulated utilization of crane 1 was 30% and the measured utilization factor 25%. The measured crane utilization did not include crane use for activities 9 and 13-15, resulting in lower crane utilization. If the simulation is run without considering the crane use for those activities, the simulated utilization for crane 1 decreases to 26% improving the correlation with the measured utilization. It is thus concluded that the simulated and measured crane utilization is well correlated.

The measured utilization was only available for crane 1. However, crane 2 was believed to have similar work load as crane 1. The utilization of other resource types is calculated in the same way as for the crane resource.

4 CONCLUSIONS

Based on case-studies and interviews with site managers, a conceptual model has been developed. Given that the construction method is widely used in multi-storey housing, an improvement of the process efficiency would be of significant importance for the construction companies, clients and end-users.

By describing the process in detail concerning activity dependencies and use of resources, it opens possibilities for analyzing the process. Problems which often occur in reality but seldom are discovered by current planning practice can be highlighted. This information can be used for future improvements.

Based on the conceptual model, a simulation model has been developed and implemented into a commercial software. The simulation model has been verified by simulating the erection process in a real world project. The real world process has been reproduced in a realistic way.

The simulation model has been run with deterministic input values. An interesting future work is thus to explore the influence of stochastic input values on the model response and of course also to verify these results against a real project.

The model can be used to improve the construction method by studying the effects of e.g. using different formwork systems, working in two-shifts or providing services outside the ordinary working day.

As the model has been implemented into a commercial software, it can be used by practitioners in real projects.

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An information management system for monitoring of geotechnical engineering structures

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ABSTRACT: Structural monitoring in geotechnical engineering projects is more than just the installation of sensors and the comparison of target vs. actual values. Monitoring is embedded in and strongly dependent of the construction process. Mechanical models for simulation of structural behavior should be simultaneously adapted according to the measured values. The arising model versions have to be stored and documented in a comprehensible way. This is only possible if both the geotechnical engineering structure and the sensor system as well as the measurement program are modeled in a combined 4D model. A meta model which enables this combined modeling of product and process model considering the aspects of model management will be presented in this contribution.

1 INTRODUCTION

Due to the high heterogeneity of soil and the very complex soil conditions construction projects in geotechnical engineering are subject to high model uncertainties. Hence these projects require continuous monitoring of structural behavior and collection of more detailed information based on laboratory tests and field tests during the construction process. The appropriate prediction of the mechanical behavior of geotechnical engineering structures prior to the construction phase is almost not possible because of the high heterogeneity of soil and the restricted number of selective, mostly expensive, tests. The most soil models used for design of geotechnical structures are not able to represent the behavior of soil structure interaction exactly. Due to the uncertain knowledge about soil conditions prior to the construction, the use of complex soil models is mostly meaningless. In practical applications models based on simple constitutive equations will be chosen which neglect essential physical phenomena. This is, particularly for construction projects near existing buildings, a considerable risk factor which causes high demand on (1) documentation of data that may be of juristic importance regarding the project and adjacent buildings and (2) the simultaneous update of predicted behavior of soil and structure.

In case of high deviations between design and monitoring data the design model and the construction method must be adapted (Faschingbauer & Scherer 2007). This enables the considerable reduction of construction costs during the construction process, ensure safety of the structure and enhance the knowledge about the soil behavior. Until now the updates of the mechanical models are usually restricted to simple variations of model parameters. Complex soil models are not considered for monitoring at all because the computing power for short reaction times is usually not available. Also the simple model updates based on parameter variations are till now done only few times during the construction time although higher frequency of updates would be required for adaption of the construction method to ensure safety and efficiency. This is because maybe 80% of the work to assign sensor data to the observed building element and also to the right construction phase is done manually by engineers and causes a lack of time for the real analysis tasks. Hence currently large data sets can be investigated only partially. The possibility to safe money or to enforce security is not used. Of course some automatically working monitoring systems have been developed in the past (Streicher et al. 2005) which are able to register data and give an alert in case any predefined sensor data are exceeding a threshold. But these are hard coded systems developed for special applications. They are practically not flexibly adaptable to the variety of monitoring problems in geotechnical engineering and they do neither allow modeling of the sensor system as part of the product model nor (semi) automatic system identification and updating of the mechanical model. The exchangeability on demand and the systematic choice of the models under consideration of complexity, accuracy and reliability are hardly supported by state-of-the-art monitoring systems, despite of the significant influence of the selection of the engineering model on the results (Smith 2005). The actual insufficient formalisation of the domain 'monitoring' and the low interoperability of the different software products support these requirements only in a very restricted range (Scherer & Faschingbauer 2006). An information system is needed which can be configured flexibly for each special application case using distributed resources for engineering analysis (services, computer power) and which provides direct access to design models, design data and sensor data.

2 OBJECTIVES

Goal of our work is to facilitate the actualization of geotechnical engineering models during the construction process and to improve the management of sensor data, laboratory test data and design data for monitoring of geotechnical engineering construction by a grid-based monitoring and prediction system.

This system should enable:

1. *integration* of distributed resources, i.e. computing power, software applications, models and data in one flexibly configurable system for parallel computation of complex mechanical models and
2. support of *assignment* of sensor data to their related design models, design data and construction phases to enable direct comparisons between design and measurement and
3. integrated *modeling* of both construction and monitoring processes as well as their linkage to product model and monitoring model
4. *management* of product models, mechanical models and model versions investigated simultaneously to the construction progress.

This contribution will discuss the second and third aspect. The support of assignment of sensor data to the monitored objects and to the construction phases needs an integrated model of the engineering product and monitoring system both from the point of view of data modeling and from process modeling.

3 APPLICATION SCENARIO

The engineering model of the structure must be evaluated and adjusted to any new situation in order to get a clear understanding of the condition of the engineering structure and to enable new and better forecasting of the future behavior. Figure 1 shows the sheeting of an excavation in different construction phases:

- Phase 1 represents the situation before the construction.
- In phase 2 the sheeting will be installed.
- Sensor 1 will be placed at the sheeting at the beginning of phase 3 where layer 1 will be excavated.

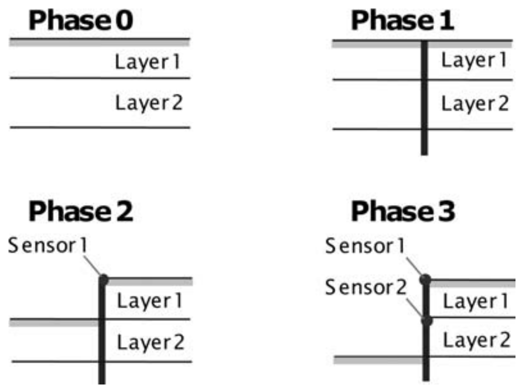

Figure 1. Application scenario of model modification and exchange.

- Phase 4 contains installation of sensor 2 and excavation of layer 2.

Each phase will be investigated before the construction process and predictions of the possible behaviour, i.e. the forecasted sensor data, will be done based on the chosen mechanical models. During the construction process the sensors will register data which have to be evaluated against the predicted data.

If the deviations are high, i.e. the mechanical model does not represent the situation adequately, the parameters of the model have to be adapted and hence the model has to be fitted to the sensor data. This task is usually done by engineers.

Two main questions arise before the adaption of the model is done:

(1) Which are the predicted data to be compared with data of sensor 1 and sensor 2? Of course we can compare only data of the same placement, direction and physical meaning.
(2) To which phases do the data belong? Sensor data of phase 3 have to be compared with predicted data of phase 3, simulated with a model representing phase 3.

So data can only be assigned if they represent the same physical fact and if they belong to the same phase in the construction process.

On the first point of view this is simple. On the second point of view it is very complex if a high number of sensors, registering data of different physical meaning are installed and if a high number of construction phases has to be considered. After the assignment of the data they have to be compared and if the deviation is too high (1) the parameters of the model have to be updated by trial and error calculations and/or (2) the model has to be changed completely if the actual model cannot represent the sensor data. Hence, there arise various models which may again have various model versions. Given that the excavation will be done in several steps and given that in each step new information about the real soil conditions will emerge, we see that the number of investigated models may be very high. This simple example shows the high complexity and the high number of models which have to be managed. Till now the assignment and model modification is done almost manually.

4 APPROACH

The effective support of observation and interpretation of sensor data by informatics methods with special consideration of the context during the construction process requires an information system which is able to represent the engineering structure itself, the sensors and the corresponding construction and monitoring processes. Hence the proposed information system for monitoring of engineering structures consists of the three main components illustrated in Figure 2: (1) the sensors which deliver data about the actual behavior of the system, (2) the engineering systems itself and (3) the processes which define the workflows of the construction process, the monitoring procedure and the model investigations. The whole system is represented by a system model.

Each engineering system is an object with object-specific properties. If we consider engineering systems in geotechnical engineering, e.g. an excavation sheeting, the properties can be of different type. On the one hand there are geometrical and topological properties, which can be represented by the structural object model. On the other hand there are the physical properties of the material. They can be represented mathematically by material laws, i.e. by engineering models. The engineering model describes the system behavior of the building. In order to be identifiable and reusable, both the structural object model and the engineering model need as a basis for their instantiation a well defined and structured data model.

Also the second part of the system, the sensors, have properties which must be described by a sensor object model and a data model. The measured values have to be set in context with the engineering model. This would be possible by object oriented modeling both of the engineering system, e.g. by an IFC building model, and also of the sensors. Complementary to the object oriented modeling of civil engineering structures the object oriented modeling of sensors is a straight forward idea which will enable to define the characteristics of the sensors, especially the kind of data provided and hence provide the basis for the management of sensor data.

Furthermore it will enable the definition of the topology between the sensors and special parts of the building. This is an important point because therewith the sensor will be linked directly to the engineering structure and hence this provides the definition of the relationship between forecasted and measured values. It is also the basic step to enable the updating of the engineering models according to the measured values.

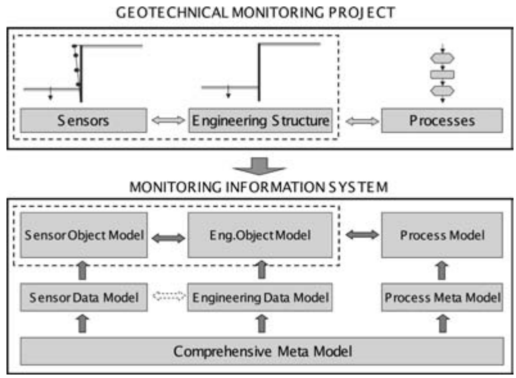

Figure 2. Architecture of the Monitoring Information System.

Of course, the authors are aware that the idea of semantic data models for object oriented product modeling and the extension for new domains, e.g. geotechnical engineering and monitoring, seems to be straight forward. Nevertheless, the high importance of data models for monitoring has been shown in several publications (e.g. Garrett 2005, Garret et al. 2006). Also the combination of product and process model is research topic in several national and international projects. The development of a monitoring system which should fulfill the aforementioned capabilities needs an integrated process and product model which considers both the domains geotechnical engineering, monitoring and model management.

All aspects regarding the combination of the engineering structure with the sensor system in one model and the linkage to a process model as well as the requirements of model management will be dealt on generic level and brought together in one comprehensive meta model in order to make the system applicable to the variety of use cases in structural health monitoring. The generic parts will be complemented by domain specific models for geotechnical engineering.

5 COMPREHENSIVE META MODEL

The comprehensive meta model for monitoring of geotechnical engineering structures should combine construction, engineering design and monitoring. Additionally the link between product and process modeling must be defined. Finally, the information logistic, i.e. the procedure of data evaluation and hence the sequence of the system tool usage, must be described by process models. They describe

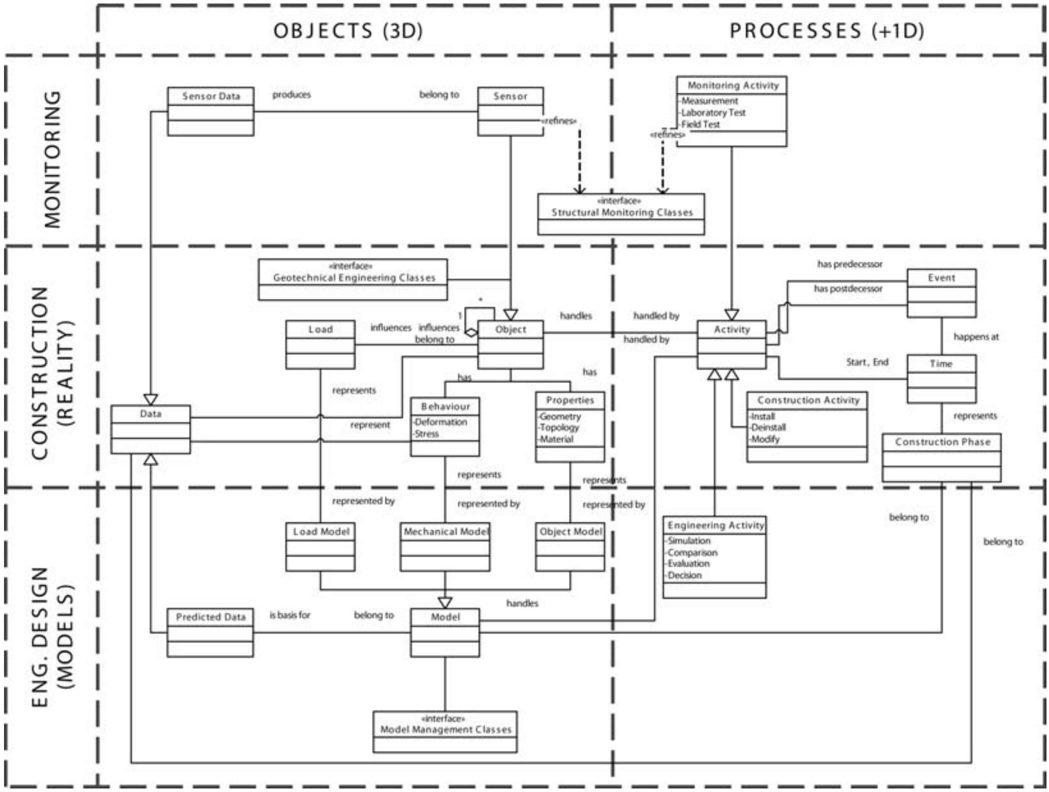

Figure 3. Comprehensive meta model.

the sequence of actions and conditions for their application. One of the most common methods of process modeling is the graphical EPC-Method, which was developed for the ARIS-Framework by Scheer et al. 2005. It has been developed for modeling of business processes. The elements of an EPC are events, functions (activities) and logical connectors. Based on these elements process chains can be built, whereas an event is the predecessor of an activity and the result (postdecessor) of the activity is again an event. This approach is used and combined with product modeling within a comprehensive meta model, partially given in figure 3. The core elements of the comprehensive meta model are the class <object> which is the central class of most product meta models and the class <activity> which is a main part of most process meta models. Both classes are connected with the <handling> relationship. Each activity can <handle> an object and each object may be <handled by> an activity. This simple relationship enables the modeler to link product and process model on the level of building elements. Important for product models used for monitoring purposes is that an object has not only properties but also behavior. In civil engineering applications behavior can be e.g. deformation, displacement, stress or other physical values. Properties, behavior and also loads are represented by models. Also these models are related to the (engineering) activities by the <handling> relationship. This enables us to integrate also the tasks of modeling or model modification in the workflow of construction and monitoring. The <models> are the basis for <predicted data> which are a subclass of <data>. <Data> represent the <behavior> of the <object> and <belong to> a <construction phase> which starts and ends with and <event>. The link between the engineering design (model-based prediction) and monitoring is expressed by the class <sensor> which is a subclass of <object>. By modeling the sensor as an object the direct connection of monitoring model and building model is possible. The <sensor data> <belong_to> a <sensor> which is part of the comprehensive object model and the activities of measurement are assigned. All the concepts used are assigned to the construction phase they belong to. This is also done for the models used for predicting the behavior. This comprehensive meta model enables the integration of all aspects of modeling, geotechnical simulation, monitoring and model management in one information space.

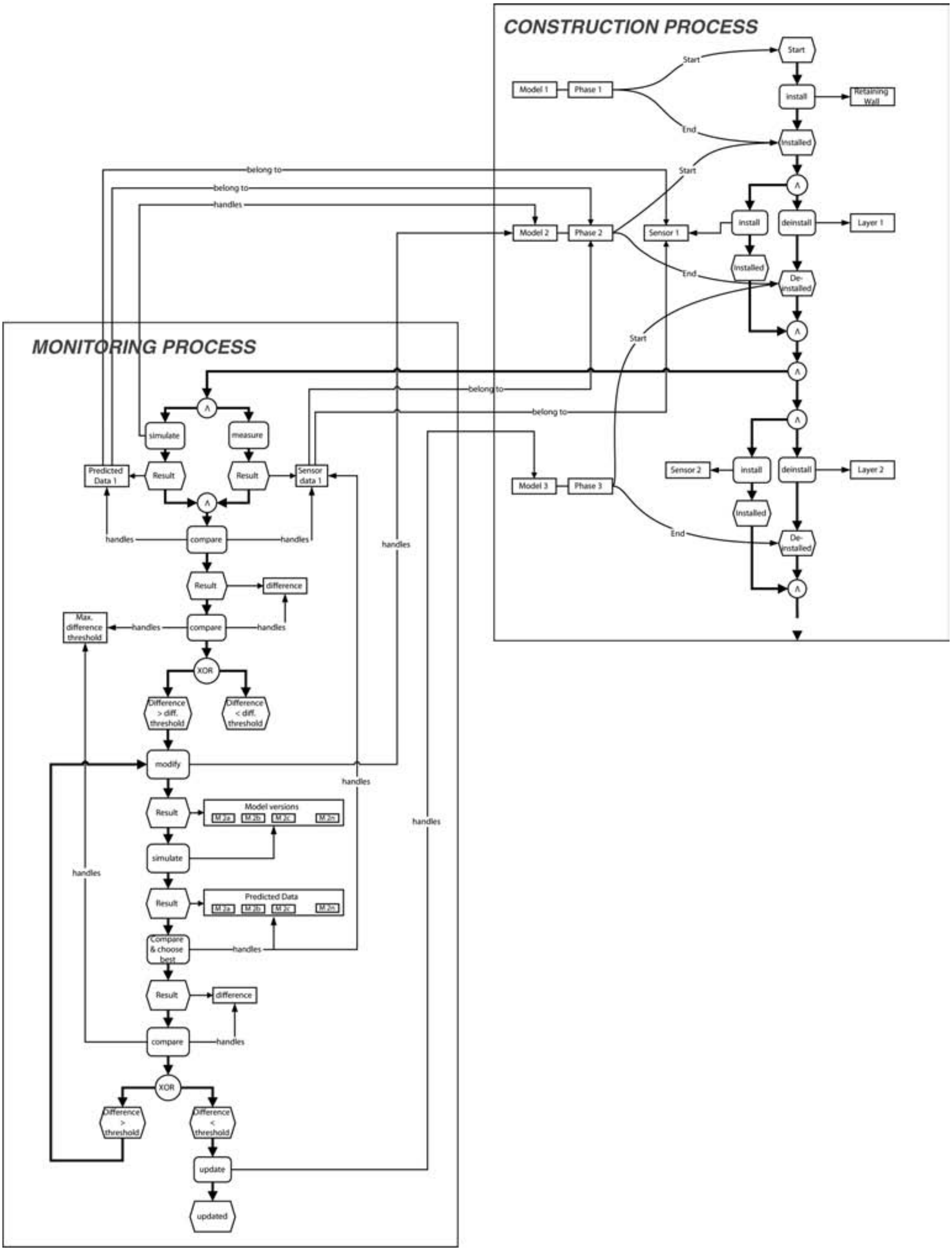

Figure 4. EXAMPLE Instance.

6 SYSTEM MODEL INSTANCES

Figure 4 gives an example of a possible system model instance of the comprehensive meta model for construction and monitoring. Both the processes (workflows) and the objects, models and data are defined in this system model. Bold lines indicate the information flow, thin lines indicate directed associations.

Leading process is the construction process which defines the construction events and activities and their assigned objects (e.g. building elements). Also the construction phases and the (mechanic) model describing these phases are defined in this model. E.g. Phase 1 represented by model 1 starts with the <START> event and ends with the <installed> event. The activity in this phase is the installation of the retaining wall, which belongs to the <install> action. During the construction process the installation of sensors is part of the model. Parallel to construction the monitoring process is executed, i.e. registration of data from measurements, lab tests or field tests and their comparison with the predicted data. Based on the results of these comparison it will be decided if the actual model represents the monitoring data correctly or not. If the model is not sufficient, i.e. the difference between prediction and measurement exceeds a threshold, the model will be modified, new simulations will be done and compared. The best fitting model will be com pared again to the threshold and chosen as the new actual model representing the engineering structure for the assigned construction phase. The models for the future construction phases will be adapted accordingly.

7 CONCLUSIONS

The primary goal of the presented approach is to facilitate the actualization of geotechnical engineering models during the construction process and to improve the management of sensor data, laboratory test data and design data for monitoring of geotechnical engineering construction. In this contribution we provided a meta model for the modeling of sensors and their topological connection to the engineering structure as well as the connection of the product models to the construction and monitoring process. This is one of the crucial pre-conditions for the linkage of sensor data to engineering models and for the automation of monitoring processes. Of course for the practical application of this approach more detailed data models for monitoring and data models for geotechnical engineering are needed. An extension of the IFC data model is intended. First steps in this direction are already done and will be further embossed. These models should consider besides the geometrical and topological properties also the structural behavior, i.e. complex material laws. In the end a modeling framework is envisaged which supports the modeling of all aspects needed for monitoring of geotechnical engineering structures. The modeling framework is the 'information core' of the whole information system and provides access to monitoring-relevant information. The semantic models will therewith support information logistics in monitoring directly. The information model can be the basis for workflow models which enable the logical integration of web services for engineering analysis and interpretation of measurement data.

The system will be complemented by the development of a model management system which should be able to manage the storage, exchange and documentation of models and model versions and hence makes the whole workflow and the different steps of monitoring and model modification more transparent and traceable.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

MACE: shared ontology – based network for architectural education

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ABSTRACT: This paper presents MACE project (Metadata for Architectural Contents in Europe) that sets out to transform the ways of e-learning in architecture and construction in Europe. It will integrate vast amounts of content from diverse repositories created in several large projects in the past, and build a framework for providing community-based services such as finding, acquiring, using and discussing about e-learning contents that were previously not reachable. Furthermore, MACE aims at providing innovative tools to search, create content and enrich it with new metadata, which can be used to support different learning scenarios. Several kinds of metadata are used in these tools to provide different perspectives on the learning content, and find new ways to combine them.

1 PROBLEM STATUS

The European Institutions, in the domain of Architectural Education, are developing an increasing range of initiatives to develop ICT Applications for their Institutional Courses, Libraries and Archives. Parallel important initiatives are being developed by private entities as architectural design studios or engineering companies run by relevant architects, portals addressing search of architectural contents into Archives and projects repositories where design documentation, iconographies and related information are stored. On the other hand, a number of Web Sites are run to guest users' experiences in the form of visit reports, discreet itineraries of visit, together with selected iconographies, interviews to protagonists or stakeholders, open forums where evaluations and experiences of travelling along thematic pathways in search of emerging approaches are shared, or solutions highlighted on the contemporary stage by users spontaneous aggregations.

But the prevailing characters of the actual European Scenario of Architectural Education and related E-Learning services are:

– the lack of a common reference ontology based on agreed rules and standards for the networking of the individual initiatives into a synergic context of semantics;
– the searching and retrieving tools are laid on restricted horizons, both in terms of extension to a limited number of repositories, the population of which is hardly known in its width;
– the indexing and encoding taxonomies are heterogeneous, non cross – recognisable through shared thesauri of terms, of which only standard- referring subsets are addressable;
– a great number of learning or information objects accessible from the web are not indexed by a standard format metadata, so that the semantic values are not comparable.

2 BACKGROUND

As aforementioned, different architecture-focused web-portals have been developed. A possible classification by categories could be: e-learning platforms, visual collectors, software resources, vertical portals, projects databases, topical search engines, materials databases and architects' sites[1].

All of them have their own importance in the architecture sector bearing in mind that each portal provides different kind of information contained in different kinds of media (image, video, documents,…), as well.

On one hand, Visual collectors and Project databases are important in architecture sector because they own databases rich in images. However, they aren't usually very structured. While Visual Collectors take on the figurative, formal, perceptive and spatial dimension of architecture, the Project databases take

[1] UNIVPM, EAAE: Deliverable 2.5: Recruiting policy for adding content from third parties. Deliverable written within the MACE project. UNIVPM (2007)

on the spatial organization of dimension and typology. Architecture Gallery (0III)[2], architypes.net[3] and VIEW[4] are some examples.

On the other hand, Material Databases have interesting and useful documentation regarding products, architecture related materials and the latest technologies in the building field available. Therefore, Material databases bring the material and technological dimension of architecture and help professional designers and students to link products-materials-technologies to buildings in order to understand the materials and technological solutions adopted in their performance. Materia[5] and Material ConneXion[6] are some examples.

Software Resources orient the students, teachers or professionals in choosing which software is most suitable for his/her work or study's need. Moreover they also guarantee constant updating regarding the latest CAD and CAM photographic touch up, photo composition, rendering and video creation software products. CumInCAD[7] and CGarchitect.com[8] are some examples.

Besides possessing a rich image repertory, Vertical portals contain critical essays and document the development of the contemporary debate on architecture. This critical dimension/part complements the project and image repertories of Visual collectors and Project databases, which would otherwise remain mute. ArchNet[9] and Arcandpro[10] are some examples.

And finally, Architects Web-sites are important because they make constantly updated material available.

3 MACE PROJECT

MACE – "Metadata for Architectural Contents in Europe" is a research project started in September 2006. It is a project co-financed by the European Commission within the "eContentplus" Programme, a multiannual Community Programme initiative to make digital content in Europe more recognizable, accessible, exploitable, selectable on the base of shared and dynamic ontology, reusable within multiple university education and life – long learning curricula for professional user.

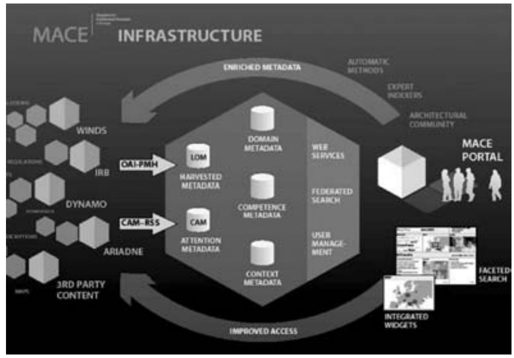

Figure 1. MACE overview.

The main assumptions of MACE is that the Expert Knowledge sets of a number of stakeholders, protagonists in the architectural domain, have to perform as the back-bone of the desired boundary-less repository of Architectural Knowledge, to be shared by the members of a world-wide community of users. Thence MACE initiates the proposition of a commonly shared ontology, terminology, series of concepts structured in a domain index, conceptual maps for the representations of the dense tissues of relationships connecting the multiform and trans-disciplinary contents of architecture.

3.1 *Objectives*

MACE main objective consists of the content enrichment of a huge quantity of knowledge resources dedicated to architectural education all over Europe, already expressed in the digital form, thence eventually available to a vast audience of students, teachers, professionals, researchers through the web, once the condition of precisely aimed access to selected contents could be made actual.

On the other hand, the aims of MACE concern the definition of a number of users' profiles, based upon the nature of their practice as stakeholders operating in the architectural domain: user profiles the designated requirements of whom have to be compared with the access path to selected learning objects in the web-connected repositories, and the inquired exigencies of whom have to serve as the reference base for the network access infrastructure technologies to be implemented, the interface widgets aimed at support of multiple selection federated research of contents.

And finally, MACE aims at establishing a cultural and organizational reference ontology, taxonomy, communication system for learning/teaching architectural design, and forwarding quality in professions, supported by a robust technological platform for

[2] http://www.0lll.com/lud/pages/architecture/archgallery/
[3] http://www.architypes.net/
[4] http://viewpictures.co.uk/
[5] http://www.materia.nl/
[6] http://www.materialconnexion.com/
[7] http://cumincad.scix.net/
[8] http://www.cgarchitect.com/
[9] http://archnet.org/
[10] http://www.arcandpro.com/

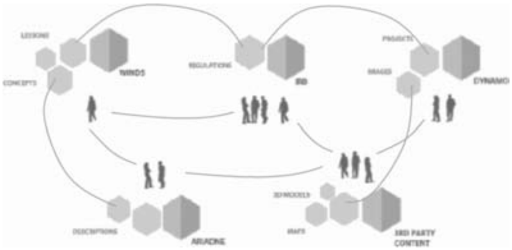

Figure 2. MACE network.

metadata indexed access to knowledge repositories on the web, operating on these principal domains:

– Education: involving higher education usually accomplished through regular courses at universities and in masters, including the Faculties of Architecture and Civil Engineering.
– Profession: including the activities usually undertaken in professional studies, like designing, tenders and contracts, technology scouting, access to regulations and standards, as well as life long learning.
– Industry: including the activities concerned with the manufacturing of building components and materials, as well as the activities concerned with the construction of buildings and in the settlement of urban areas.
– Public Administration: offering services supporting the activities related to life-long education, real estates maintenance and promotion of quality in architecture, connected to strategic domains as territory and cultural heritage, as well as tourism.

Basically, the idea is to provide convenient and effective ways to network the already existing repositories enriching their contents with new metadata, making connections between contents accessible to the user, thus enabling inter-repository navigation paths, and finally providing a search interface that allows users to benefit from multiple types of metadata for content retrieval (See Figure 2).

3.2 *MACE consortium*

The MACE consortium consists of eleven partners from academia and industry. It builds on the WINDS project (Web based INtelligent Design tutoring System, an EU-funded E-Learning Platform containing 21 courses spread over Europe. It offers an on-line Virtual University for Architecture and Engineering Design through cognitive approach application to teachers' Course Authoring and Students' design modeling), in the ARIADNE Foundation (one of the early pioneers on a vision of "share and reuse" for education and training has a large amount of heterogeneous content objects and thus makes ARIADNE a good environment for trying things out like Federated Search and connection of distributed content repositories. It has distributed learning object repository called the "Knowledge Pool System"), in the ICONDA (Fraunhofer IRB – Information Centre for Planning and Building – hosting 650.000 references and referencing 300 journals monthly – offers databases for online utilization divided into three categories: bibliographic databases, full text databases and research project) and DYNAMO (Architectural Projects Repository – multimedia platform filled with a permanently growing collection of concrete design projects, in the field of architecture, offering students/teacher and professionals designers a rich source of inspiration, ideas and design knowledge – K.U. Leuven, complemented with 5000 learning objects from many different universities worldwide through ARIADNE and the GLOBE network of learning object repositories).

4 MACE APPROACH AND METHODS

MACE assumes that the two-fold approach (of proposing a robustly structured domain Expert Knowledge – based indexing environment, referring to the major instituted Thesauri, Norms and Regulation systems, professional best practices and business cases, operated in parallel with an open community participation- oriented and user-driven approach) must not be seen as contradictory, in as much the same knowledge contents held by the main stakeholders is the subject of an uninterrupted contextual and historical evolution, which the vast communities of users contribute to and withdraws from. Through this vision – and referring to a robust cognitive and didactic approach – MACE proposes the structuring of content enrichment network system, aimed at making available the possibly largest majority of Architectural knowledge repositories accessible by a selective federated search, based upon conceptual indexing. Of which the responsibility for the proposition and "initiation" is assumed by the domain experts, but progressively shared, newly shaped by community – practiced research paths and paradigms, updated and innovated by the emerging main streams of architectural thought and practice of new protagonists. The MACE technological infrastructure is in charge to capture from users, make visible, than establish as emerging users' profiles. To make this ambitious project actual MACE initiates from connecting the architectural knowledge repositories held by the Educational Institutions, recognising their central role in the process of production/dissemination of contents for education and training of future experts; even more for their position along the logical process of contents' representation and competence acquisition.

MACE aims at quantifying the quality of the metadata necessary for the description of a significant digital content in E-Learning (Learning Object) sample essentially from the semantic point of view. In parallel, digital contents can be articulated in structured contents (documents, cases and so on) and simple content (photo, drawings, etc.). It is been necessary, preliminarily, to define the competence fields qualifying the expert user categories set up for indexing and, consequently, the content classes.

4.1 *MACE competence fields*

Three principal competence fields are been identified within the architecture domain: Architectural Design, Building Technology and Construction Management. Building Technology concerning the fundamental competences of technological design in architecture, with the scope of enabling description and control of the design solutions at technological level (materials, components, regulations, performance analysis, technological sections and nodes), highlighting their impact on design strategies and Construction Management concerning the construction process, which is naturally uncertain, non-repeatable and nomadic, extremely complex from an organizational and technical point of view in its variability and in the intensity of the relationships between the operators and their materials.

4.2 *MACE taxonomies*

MACE information requirements are represented by three taxonomies:

- Media: concerned with the description of the form of the digital object, the format, its structure.
- Domain: concerned with the content of the digital object, mainly related to the description of the architectural object (e.g. the building, the urban area, connected to its operational set of knowledge) in terms of the basic information and of the processes that are involved with design tasks, or construction competences, normative aspects, and so on).
- Application: describing the information related to processes involved with the object, like planning for courses in architecture, etc.

4.3 *MACE users' profiles*

For each application domains the following users' profile have been identified:

- Education: professors/students of architecture – building technology and construction management involved in teaching, curriculum planning, personal and social learning activities.
- Industrial and profession fields: engineers and architects involved in design, construction management of buildings and urban areas as well as in life long learning.
- Public administration: policy makers and decision takers involved in the administration, in the promotion of built and cultural heritage.

4.4 *MACE metadata*

Bearing in mind that MACE is mainly focused on architecture engineering and construction education, one of these standards used is the Learning Object Metadata (LOM) standard, used to describe MACE educational resources. Learning objects (LO) are defined here as any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning, and Learning Object Metadata, a data model used to describe a learning object and similar digital resources used to support learning as well. Learning Object Metadata distinguishes between nine metadata categories (general, lifecycle, meta-metadata, technical, educational, rights, relation, annotation, classification). LOM incorporates and extends several fields of the Dublin Core metadata element set which is standardized as ISO Standard 15836-2003. The fifteen Dublin Core metadata elements are used to describe a resource in general, e.g. the title, creator, format, coverage, etc.

The purpose of this learning object metadata is to support the reusability of learning objects and the improvement of the interoperability between different Learning Objects Repositories (LOR). This metadata can be enriched manually or automatically and is classified as content and domain metadata, context metadata, competence and process metadata and usage related/social metadata.

Content and domain metadata contains information about the learning object and its content: domain of the learning object, what the content is about and the technical properties of the object. In MACE, learning objects are classified according to various different descriptions and rely on LOM standard to capture these descriptions.

Context metadata is used to define the context related aspects of the overall taxonomy to be used in MACE, the corresponding metadata schema and its relation to LOM. Contextual metadata will provide a categorization of entities with respect to similarities in their context metadata and enable more advanced search than traditional keyword search can offer. Even though the MACE system will deal with the digital contents describing real world objects and not the objects themselves, it makes sense to distinguish between two categories because they have different metadata associated with them. Fortunately, the LOM standard allows for more than one metadata record per content object. MACE will make use of that by having different LOM records linked to each other, one for real world and one for digital content. The different context metadata included in MACE are classified as: architectural context, physical context, social, usage and role context and technical context.

On the other hand, Competence metadata are used to specify the competences that education should aim at and to tag contents in order to make them reusable and retrievable for educational purposes. Competence metadata describes abilities a student needs before starting a particular course.

And finally, Usage related/social metadata describes what users actually do with learning objects: explicit user feedback captured through annotations, e.g. from folksonomies and blog/wiki comments, the context, in which a learning object has been deployed, searched and used activities of users, to support personalization and recommendations.

4.5 *Building products classifications and Thesauri and the classification metadate (LOM 9)*

To connect content metadata to MACE, a common structure is created: the MACE Application Profile (AP). This defines the different possible terms and values that are identified to describe architectural content. The list of classification terms is derived from different existing standards for example CI/SfB and UNICLASS, such as the Getty Thesaurus, that's a very complex and complete thesaurus and so the idea has been to use it as a reference, like we are doing with CI/SFB and many other taxonomies.

- CI/SfB – Construction Indexing Manual: an international widely used classification system for product and materials documentation in the building industry. CI/SfB includes four main table.
- UNICLASS – Unified Classification for the Construction Industry: a classification scheme for the construction industry in architecture and engineering. It defines in fifteen tables codes for a multi-level international classification of building and civil engineering elements, spaces, documents, phases, materials etc.
- The Art & Architecture Thesaurus from the Getty foundation – Repertoire of AAT Getty Vocabulary: this structured vocabulary it is used to improve access to information about art, architecture, and material culture and it includes 133,000 terms, descriptions, bibliographic citations.

The MACE Application Profile contains nine different categories of metadata. LOM 1 to 8 describe administrative and contextual information about the Learning Object, such as author, date, filetype, educational properties and access rights, while LOM 9 Category describes classifications of the learning object within the MACE classification system. Possible classifications include many different classification criteria with different possible values, e.g.

Figure 3. MACE Application Profile – Construction Form.

function, style, form or structural information. The example below shows some possible classifications:

- Building Element: based on CI/SfB, Component Parts – Table 1 – SfB classification – Classification of the building elements;
- Construction Form: based in CI/SfB, Element Construction form – Table 2 – SfB classification – Classification of the building elements (See Figure 3);
- Structural Profile: based on Repertoire of AAT Getty Vocabulary about the definition of structural issues;
- Form characteristics: based Repertoire of AAT Getty Vocabulary about description of the formal aspect and its spatial configurations. Topographic and geometric features that influence the form and the shape of the urban space; or the architectonic and/or design object and the reciprocal formal relationship in the space;
- Construction management: based on UNICLASS, Management of construction activities/project management – Table C-C5/C9, ISO 12006 – Management function concerned with defining goals for future organizational performance and deciding on the tasks and resources to be used in order to attain those goals by means of well developed plans (planning), management of the aspects related to the effective achievement of a standardized level of performance (quality), management of the aspects related to the preservation of human safety and good health, during the construction phase (health and safety), management of the aspects related

to the environment, during the construction phase (environment).
– .....

It is not necessary that a repository will follow all these classifications. In many cases, only some of these categories are required, e.g. Functional Typology, Form Typology and/or Technical Performance.

5 MACE IN BUILDING TECHNOLOGY AND CONSTRUCTION MANAGEMENT DOMAIN: APPLICATION EXAMPLES

In order to assure the efficiency of the keyword search is important to carry out a rigorous definition of the domain. In MACE, the analysis and development of the building technology and construction management domain has been done by different domain experts after a thorough study of the already existing standards and thesaurus, such as CI/SfB, ISO 12006-2 and UNICLASS, and under the point of view of expert's personal experiences.

Building Element, Construction Form, Material, Technological Profile, Technical Performance, Systems and Equipments can be found in the Application Profile of MACE and can be found in some Learning Object of the repositories included inside MACE, for example in WINDS.

Building construction practices technologies are the result of a long evolution process, through which experience and knowledge transmission has made buildings' performances extraordinary increase possible. With the aim of supporting ability to recognize and understand the innovation features inserted into the developing materials, components and building systems, exemplary cases of historic architectural experiences are presented, highlighting the progressive acquisition of reported knowledge domains and integration into design solutions. The pragmatic approach to architectural design provides a robust design methodology, founded on the principal scope of building technology domain: to enable description and control of the complexity typical for architectural design themes, like quantity, extension, heterogeneous nature, individual specificity of the set of connection and relationships that cross-influence the decision scenario, the components' production and site construction constraints of the actual building process, highlighting their impact on design strategies and knowledge domains integration and hybridization.

The educational aim is to exercise students-designers' ability to make motivated and autonomous choices on the base of acquired knowledge of exemplary architectural solutions and market available products. For example, the student is in charge of the development of the building envelope. Each student

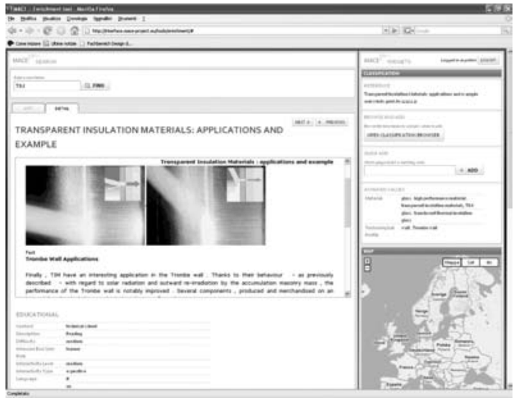

Figure 4. An example of result in MACE Portal.

is invited to issue his own personal Idea of Architectural solution for his Design Theme, as the motivated choice of the architectural language approach significant to him, expressive of his favourite values and moods. Student will also have to examine the applicability and adaptability of technical solutions proposed by case studies in his own design, learning to examine parameters of similitude and difference to match his specific theme, context and design intentions.

Student will have to search in MACE Portal, inside the currently integrated contents repositories, for the information sets describing the context and environment of the his project, recognise the available resources' layout (technical knowledge, traditional building technologies and innovation products/ materials,...). Combining thermal insulation and transparency is certainly of basic importance in the innovation of envelope systems: for example he search materials able to grant both transparency and thermal insulation at the same time – Transparent Insulation Materials (TIM) – an innovative material – a new class of composite materials, associating good light transmission and good thermal insulation or transparent insulation materials. The system provide different links to contents related to the searched keyword, for example: the physical structure of the material, application in the Trombe wall, examples of glass translucent thermal insulation and related products and students can improve their knowledge by navigating from content to content.

In the construction sector, especially when using general contracting, it is clearly visible the separation of responsibility for designing from the responsibility for construction. However, the designer has always supervised the construction of the work. In practical terms, this has come to signify that design and management are two sides of he same coin. Therefore, the knowledge of different management aspects becomes also necessary along the learning phase of an architect student. For this reason, MACE not only provides knowledge related to the architectural design and technological design but also to knowledge related to construction. Health and Safety management contents, quality management contents, environment management aspects, time management techniques, as well as costs and logistics on site aspects can be found in some of the repositories included inside MACE. All these MACE contents are expected to be used in educational scenarios, providing instructors new, more structured and specific digital information to prepare their courses, as well as real cases, examples and tests to facilitate the students the development of their works and their personal evaluation. One example of Application Scenario could be a situation where students are asked to develop the part of a Construction Project Quality Plan related to the Cast-in-place Concrete Structure. Students should define all the necessary operations, measures and controls to assure that all the Cast-in-place Concrete Structure is well executed. In this case students logs into the MACE portal and access the search service to start the search of keywords such us: quality plan, cast-in-place, concrete. The system provide different links to contents related to the searched keyword as well as a group of associated topics, such as Construction management, Project documentation, Quality regulation. Therefore, students can improve their knowledge by navigating from content to content.

6 EXPECTED RESULTS

The main results – to be designed, implemented, than operated by a Consortium of Partners that is meant to continue its activity after the European Commission co-financed support – are as follows:

- direct access through the MACE Portal, supported by the MACE web infrastructure and technical platform, to a vast number of architectural knowledge spread on the European and world-wide network;
- promote the progressive compliancy for the indexing of architectural knowledge contents to a community – shared, dynamic ontology and taxonomy assumed as the reference "State of the Art" Tool for indexed;
- allow the use and reuse, within the educational framework, of contents made accessible by selective & federated research through the MACE platform and widgets, by metadata indexing on the ever – adapting taxonomy, interpreted by Application Profiles issued by experienced holders, but continually updated by the spontaneous participation;
- integrating LOMs (Learning Objects Metadata) with the Application Profile, creating a conceptual and technical infrastructure by connecting contents by metadata comparison, connecting the existing communities of interest active in the architectural domain;
- allowing cross queries on local and remote Repositories, integrating all the available resources available on the web, by enriching contents through the application of the whole set of metadata.

7 CONCLUSIONS

To conclude, this paper presents MACE, a European initiative aimed at enriching and connecting existing architectural domain portals and their contents, providing a unique single access point or interface that contribute enormously to the learning experience.

One of the important applications of MACE is the capacity to enrich contents with various types of metadata, enabling multiple perspectives and navigation paths, effectively leading to experience multiplication in technology enhanced learning about architecture and design. By this way, MACE creates an open system and provides incentives for actively enriching and sharing knowledge.

On the other hand, MACE establishes connections between concepts across repositories in order to relate items and improve the user's understanding. Following the same objective, MACE displays metadata values directly in place supporting a better judgment of the relevance and context of a single piece of information.

And finally, MACE is used to search concepts in an intuitively way enabling directed search and browsing of contents with respect to features relevant for architectural knowledge in a unique combination. The underlying weighted activation model fosters understanding how metadata values and/or search terms relate to each other.

Actually, the MACE consortium is creating a first prototype, which will be revised and improved. For this reason it is obviously too early to assess the impact of MACE, and to measure its added value compared to the services offered by individual repositories.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Future directions for the use of IT in commercial management of construction projects

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ABSTRACT: The construction industry uses standard 'off the shelf' software packages for many of its major activities such as, drawing packages, accounting packages and project management packages. Yet standard packages are not used for commercial and commercial management aspects of operations, in a similar manner. The existing packages on the market are diverse and lack functional integrity. Some implementations of new commercial software in major companies have resulted in grave challenges and risks to the business. Due to the significance of this area to the healthy operation of construction companies and construction projects it is important to explore why there is little focus on this area. In order to investigate the reasons, a literature search on the use of IT in the construction industry was undertaken. It was found that commercial systems have received very little attention and focus from the construction IT research community. This paper reviews some of the existing literature, in order to emphasise this gap in research. It urges further research in this critical aspect of managing major projects. The paper further proposes an approach that can provide inter-operability between the different formalisms, models and data related to construction. This approach can integrate the data, processes and services at both business and technical levels. Such an approach can assist in efficient and speedy integration of commercial systems with mainstream project management systems.

1 INTRODUCTION

Commercial management packages within the construction industry are wide-ranging and complicated to use. The current packages do not support many of the important aspects of the detailed commercial processes. The problem magnifies when companies attempt to implement new systems, where companies face significant challenges during the delivery phase of new software. Commonly the requirements have been poorly understood and a coherent plan for change over has not been devised.

Commercial management systems appear to vary in design from company to company, with the absence of a commonly used IT package that is suitable for use in the construction industry as a whole. For the administration of construction contracts, much of the administration tasks are standard practice with the basic contract administration being governed by The Housing Grants, Construction and Regeneration Act 1996. Standard IT packages are greatly used in many other industries. The construction industry has adopted some standard 'off the shelf' software successfully, such as drawing packages, accounting packages and project management packages. Yet, is there something significantly different about each construction firm that means IT systems can not be developed for commercial management in a similar way? Can the systems that are in use be improved further so that time and money can be saved? Could the different construction professions and parties to the contract integrate their IT systems to save time and money and reduce human error? If these systems can be developed why has this not happened yet?

Is there a fear that the IT systems could replace the commercial management and quantity surveyors? This could not be further than the truth. The possibilities of commercial IT development could provide significant improvement to commercial practices and would not lead to replacement of the staff in commercial positions. Much of the decisions made by commercial staff on a daily basis derive from the individual aspects of a project and the associated risks involved. There is a requirement to make an informed and educated opinion on maters of Law, risk, programme, logistics and many other facts or external factors. Commercial staff are required to provide suitable commercial management strategy and control to a given project or portfolio of projects. The long terms shortages in the industry of competent commercial staff should welcome any tools that facilitate better practice and time saving or reduction in repetitive practices. This in turn could allow them to concentrate on the intricate risk & financial management aspects and development of good working relationships with other key project team members. Ideally commercial departments would provide an increased service to the construction industry and achieve higher standards, reducing risk and disputes in the process. Can IT be used to facilitate this goal by saving time and streamlining processes elsewhere?

Faithful & Gould Ltd, a medium sized Quantity Surveying (QS) firm in the UK attempted to implement a new commercial management software package for the UK wide cost consultancy. A catalogue of errors occurred in the implementation of this system leading to dramatic consequences. Faithful & Gould Ltd rolled out a new management accounting IT system in circa 1999 that was to improve their commercial billing and commercial management systems and bring about great change and benefits to the company and clients alike but, the system roll out was a complete failure. The poor implementation strategy that was to manage the change over to the new system, meant huge amounts of data was lost and the company struggled to bill clients and receive monies into the company accounts as a result. As a direct consequence of the failed implementation, Faithful & Gould Ltd came close to bankruptcy. They were subsequently bought by WS Atkins group which secured the company's future.

Walmsley (2007) reports on a catalogue of errors in developing and implementing a tailor made commercial system for a major contractor in the UK. These errors have led to significant financial impact on the company, during the transition. Due to confidentiality issues, many of these problems have not been widely reported.

A literature search into construction IT research reveals that there is little work specifically on commercial contract management. This is perturbing as there are enough difficulties and disputes in the UK construction industry without further hindrance. Many disputes are documented as being caused by poor commercial management and administration (Furmston 1996). Many of the commercial processes required in construction companies are repetitive and the processes are documented in the standard types of construction contracts adopted in the UK (Sun 2003). Can basic failures in contract administration such as: late payment to suppliers and sub-contractors, lack of payment notices, poor change control and lack of final account information be improved upon if the IT systems are improved?

This paper searches the existing literature for some direction and guidelines. There are little guidelines. Furthermore some of the few existing suggestions appear impracticable. The paper provides an elementary high level requirements map for commercial management systems and appeals for more research in this critical area.

2 ICT IN THE CONSTRUCTION INDUSTRY

Globalisation of economies brought about by the IT revolution has produced large changes in most industries (Baldwin 1998) and led to advanced industrial nations trading together is a virtual environment (Brandon 1995). Many industries boomed, telecommunications for example, yet others have stalled or contracted (Sun 2004).

It has been stated that the UK construction industry is seriously lagging behind the aerospace, finance and telecommunications industries in the development and use of IT (Latham 1999). However, most of the business processes and work that surround any construction projects now rely on IT systems and tools to design, inform, manufacture, process and communicate information and like any other industry where these processes are required, IT appears to be utilised (Alshawi 1999).

In terms of future directions for ICT in the construction industry, Construct IT in the UK developed a vision for the use of ICT in the next ten years(Sarshar 2000 and 2002). This vision was further adopted by CIB Working Commission 78 (Amor *et al* 2001). This vision was based on extensive literature search and discussions amongst experts and academics. It consists of seven major themes:

1 Model driven as opposed to document driven information management on projects.
2 Life cycle thinking and seamless transition of information and processes between life cycle phases.
3 Use of past project knowledge (/information) in new developments.
4 Dramatic changes in procurement philosophies, as a result of the internet.
5 Improved communications at all life cycle phases, through visualisation.
6 Increased opportunities for simulation and what if analysis.
7 Increased capabilities for change management and process improvement.

These themes do not include any intention to research into the key legal aspects the standard contracts and the constraints these impose on the use of IT in the construction industry (Amor *et al* 2002). This clearly has a bearing on the research directions of the construction ICT community.

Another key researcher in this area, Alshawai (1999), has provided a review of the application and use of IT in the construction management of projects from an industry and research perspective. He gave an overview of major functions and impact of IT to the general performance. It was recognized that post contract functions are highly dependent on gathering and presenting information; this is costly and time-consuming and the processes that are undertaken to fill these functions are usually unstructured. Manipulation of information can not be done manually it needs to be managed electronically and presented with the correct level of detail. Alshawi (1999) mentions producing reports in the study varied in structure from one site to another and that information sent to head office was in different formats and he suggested process re-engineering is required before successful implementing patient of IT.

Alshawi (1999) suggests deregulation of professional roles and organisational systems in order to increase competition between professions. The authors question if this suggestion, as deregulation of professional roles and organisational systems will result in people being unsure of their job roles limits and where their boundaries are. Another suggestion was that clients should demand a better service. The authors are in full support of this proposal, however Alshawi (1999) continues to claim that the client should be more aware of the industry's failings. The author questions if this is a positive step. This study also stated that the industry must realise that they were facing long-term recession and overcapacity. However RICS indicates that quantity surveyors are in great demand (RICS 2000).

In short advances in ICT are not likely to be a key driver in imposing major change in the current structures of the industry. ICT systems need to respond support current structures and professions, reducing the barriers between professional communication, rather than eliminating professions altogether.

Carter conducted an EU funded research (titled eLEGAL) on the use of ICT in construction contracts. His findings demonstrate that Paper is still used in for the use of large quantities for the administration of contracts but this is not due to an unwilling construction industry, simply the failure to establish legal qualification within contracts (Carter *et al* 2001). Carter *et all* (2001) recognised that advances in IT could be used to enable the construction industry to manage large construction and engineering projects by way of assisting the co-ordination of the 'virtual enterprises' that often are used.

Carter *et al* (2001) also recognised that that there were several areas of legal uncertainty that threatened the adoption of such advances for the management of contracts and undertook a study called eLEGAL. Carter *et al* (2001) was aware that without some acceptance of and a move towards defining IT as legally admissible then many areas that could benefit from the use of IT would not be able to gain from such assistance. Legislation is now able to support the use of IT in business throughout the EU but, the standard forms of contract adopted in the UK Construction Industry do not make provision for the use of IT as yet and therefore, the eLEGAL project concluded that the use of IT to support contract practices may not be admissible (Carter *et al* 2001). According to Carter *et al* (2001) the construction industry is failing to adopt IT for the management and administration of contracts.

Since Carter *et al* (2001) wrote the Industry failing to adopt IT for the administration of documents the, JCT 2005 has been published and the new suite of contracts does make some provision for IT to be included within the contract (JCT 2005). Claus 18.1 allows the parties to agree the medium for which communication and general administration of the contract can be undertaken. However, in the guide notes to the JCT 2005 suite of contracts it is mentioned that the contracts did not go further to adopt and supports the use of IT for the management of contracts as there remains much disagreement within the Construction Industry to it's legality and authority.

3 MANAGING CHANGE, IMPLEMENTING NEW SYSTEMS

Another premise of this paper is that several construction companies have faced critical challenges in implementing new commercial management systems. For this reason some literature in change management during the introduction of new systems were examined to establish if this problem is only limited to commercial management systems. This was certainly not the case, and there is much to learn from change management literature.

In a study of a large project, the new Terminal 5 at Heathrow Airport, two types of innovation were identified, 'bounded' and 'unbounded' (Harty 2005). The research team aimed to explain an alternative way to understanding the 'unbounded' innovations within the construction industry using sociology of technology concepts. The study was seen as an exciting opportunity as there was to be 500 or more contractors on site and was known as one of the biggest construction projects in the world at that time. Harty (2005) explains that the employer (BAA) for the project was keen to role out a new system of 3D Auto CAD. The study was undertaken over an 18 month period on site. One of the findings of the study was that the system to be implemented was not actually capable of delivering the idea's or visions of BAA. The 3D AutoCAD system did not have the functionality to carry out the tasks required of the engineers and drafters and the system could not be used for drafting design as well as manufacture (Harty 2005).

The system integration methods in the study of Heathrow's Terminal 5 alienated some users and break out systems developed as the staff were determined to carry out their duties and get the project completed successfully (Harty 2005). The break off systems developed to enable actors to work rather than wait for further development of the software systems (Harty 2005).

Harty (2005) did not investigate attitudes to change and adoption of the vision and there were no references to the attitudes of the employees and sub-contractors to the adoption of the vision. These factors are interdependent to the success of any change (Hazzan 2004). Harty (2005) Quotes:

"The focus groups were an attempt at alignment. Efforts were being made to engineer a built victory generously a system of 3-D CAD software and practices but crucially with more than one system builder and with a number of ideas and visions informing its assembly none of which had the ability to override others or persuade them to change."

Harty (2005) did not mention if the rank structure was in place, if any prior discussions had been undertaken with the team members or if focus groups were set up. Similar research was carried out to explore the problems with introducing any form of management led change; aimed at understanding change within project-based organisations (Bresnen 2005). Bresnen (2005) explains that the research was conducted by applying a framework to two case studies on two separate UK companies that were applying management led change in the form of new IT Systems. The study also analysed the reaction by the project centralised team to resist the change. The author questions why they only investigated the resistance to change and not items or issues that inhibited the change in order to understand any resistance found. Bresnen (2005) also found that the diversity of the project managers systems throughout each company, as well as their attitudes, had considerable influence on whether the systems were accepted and therefore successful adopted by the firm as a whole (Bresnen 2005).

"The difference between project-based organisations compared with other de-centralised organisations is the practices of each and, therefore the spread of power of each are different" (Bresnen 2005).

Bresnen (2005) states that this results in the implementation of change throughout a company is more difficult as a result and will vary across the regions.

There needs to be a sharing of interest between the project teams and head office management (Bresnen 2005). Implementation is more successful when management are selective to who can be included in planning and implementing change within an organisation (Hazzan 2004). Those considered as 'best of breed' should be chosen to help implement the changes they will have greater knowledge of what is required (Katranuschkov 2006). Least resistance is encountered from those who have the power and knowledge of the new systems, if they are able to put this knowledge to use (Hazzan 2004). Alpha project managers remained outside the system in a 'not broken doesn't need fixing' attitude to what was seen as a redundant system.

When involving project managers, those who were respected by their peers the resistance to change was influenced by these individuals (Bresen 2005). Project Managers that didn't meet regularly could not share their opinions or knowledge to influence change positively. However; they also couldn't gain solidarity to resist the changes being implemented (Fernie 2006). Successful change reinforces and does not undermine existing systems (Hazzan 2004).

Project Managers have admitted fictitious reporting to show head office only the successful results (Bresnen 2005). Bresnan (2005) identifies that it is important for the senior management and the project managers at regional level to have the same goals to overcome this. However, Bresnan (2005) did not mention if that those who implemented the change first improved the processes or if there was an incentive to succeed, such as the bonus scheme.

Woodward *et al* (1994) studied change management during the implementation of a cost management system. The purpose of the study was to describe the philosophy behind the need for change (Woodward *et al* 1994). However, there is no mention of whether the study was a success. The findings of Woodward's study are inconclusive and the research methodology questionable. Woodward *et al* (1994) claims that the traditional role of a quantity surveyor cannot adequately cover the cost management discipline in today's construction industry and that this adds to the cause of a budget overspend. The authors questions this finding as the role of the quantity surveyor is dependent upon the work given to the quantity surveyor from the employer. It is too simplistic to rule out the role of the quantity surveyor.

4 PROCURING COMMERCIAL MANAGEMENT SOFTWARE

There are various software solutions on the UK market that are developed to aid the management of contracts. Many software suppliers to the construction industry now offer impressive solutions that are delivered as modules or packages that can be bolted together to form a fully integrated business IT system. The quantity of suppliers that produce and sell such products and services in the UK are so vast nowadays, it is not possible to list all of the products on the open market. On the whole the IT supplier's advertise their products as standard package software that is already designed and developed specifically for the construction industry, which can be tailored upon delivery to meet the customer's individual requirements. This is a credible way of ensuring their construction company customers are satisfied with the product they have purchased and is aimed at delivering products that will meet the individual business requirements of the construction orientated customer at a cost much less than that of the bespoke software. (McConnell 1997).

It is therefore critical for construction companies to fully capture the requirements of their systems before they embark on purchasing new software, and test their software against these requirements. The range of task within the management of contracts is extensive and contracts are stipulated in many areas by the constraints of timetables and stipulated dates within a contract. It is important that the procedures and tasks to be carried out are done so in an efficient manner if the required documents and information is to be presented and the tasks are to be completed satisfactorily by these deadlines. Failure to meet these deadlines can incur financial penalties imposed by the contract and, result in a breach of the law pertaining to the administration and government of construction contracts (Brandon 1995).

The administration and management of the construction contracts are not the only procedures and tasks a construction company has to undertake. There are many other business management procedures that are required for the firm to function successfully. These processes are required for a department to function. Figure 1 illustrates an overview of the departments generally required within a construction firm, although this can differ from company to company. There is a need for some level of integration between the activities of some of these departments.

Focusing only on the management of contracts, a summary of the common processes involved is shown in Fig. 2. This figure highlights the range of tasks expected as a minimum, although some variance to this is probable, dependant on the stipulations within a particular contract.

Each of the above procedures can consequently been expanded into more detail. Figure 3 provides an example.

In order to capture the requirements adequately, and be able to test and implement the eventual system effectively, there is a body of knowledge in the software industry, termed the Systems Development Life Cycle. In this approach the development of an IT system is divided into several stages. These stages together called the development lifecycle (Maher 2006). The management of an ideal development project is extremely complicated and therefore the stages are broken down into manageable chunks (Sommerville 2007).

The requirements of the commercial management software then need to be integrated to other construction information, in order to produce a concurrent engineering workbench, allowing collaboration between key stakeholders such as quantity surveyors and project managers. Ghodous (2003) has developed a methodology for construction of ontology for the integration of the two phases of design and planning during construction projects. She has also considered the web services as a technology which provides the generic services shared between different agents and specific services for each agent. A case study in the field of designing and planning the thermal properties

Figure 1. Typical department within a construction company.

Figure 2. Range of tasks within a contract.

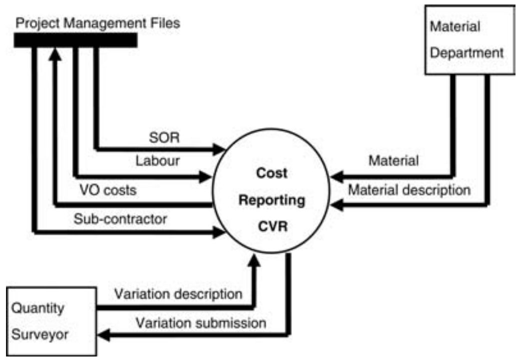

Figure 3. Description of ideal variation management system.

of a building has been conducted to validate this proposed architecture (Ghodous 2003).

This paper explains this approach. The authors intend to extend this model to incorporate the commercial management aspects of construction projects.

5 PROPOSED APPROACH

The proposed approach considers the modern view of product development (Sriram 2000) (Gero *et al*. 2002) (Gero *et al*. 2008) (Ghodous, 2002) based on communication and is based on concurrent and collaborative engineering approach (Kusiak, 1993) (Prasad, 1997) (Chawdhry, 1999) (Ghodous, 2000) (Prasad, 2001) (Roy, 2002) (Sobowloski 2005) (Ghodous 2006). Concurrent engineering is concerned with the reduction of delays by the realization of all processes simultaneously and in a distributed fashion. This concept has been extended to improve the cooperation between participants in product development. This results in improving quality, overall costs, and characteristics of the product (i.e. the building) as well as the development processes.

This new mode of work requires a thorough rethinking of methods, organizations, techniques and tools at all stages of product development.

Figure 4 shows this approach based on shared knowledge. There is a common knowledge representation and each agent (person or software) during product development, can access information in this area of shared knowledge and contribute to this information. In this approach, the clients can see the current state of the building on-line and provide their opinion. The designers, engineers and quantity surveyors work concurrently and communicate easily. The modeling and communicating information in this environment is complex because the information is:

– Multi-disciplinary: several disciplines and expertise such as engineers, quantity surveyors, project managers, and subcontractors are involved in the development of a system. This makes the searching and layering of information more difficult.
– Variety of agents: different people or different software are involved in different stages of development for example design, planning and construction.
– Use of subcontracting: Several companies are working on one or several parts of the overall project or on different projects.
– Complexity of the types of products used in industrial systems: a significant number of components and assemblies come together, some in a pre-assembled fashion, and some built on site.
– The complexity of the representation of products: engineering systems and their functions are represented through formalisms: symbolic, text, graphics, analytical and physical with different levels of abstraction.
  - Graphical Complexity: The nature of three-dimensional objects much more complicated tasks of conception. Although the objects are sometimes represented in 2D, often a 3D representation is necessary for full understanding of forms during the design.
– Lack of a generic design methodology: in the case of routine concepts there are methodologies and a common representations, but in the field of innovative and creative design there is no consensus and common methodologies.

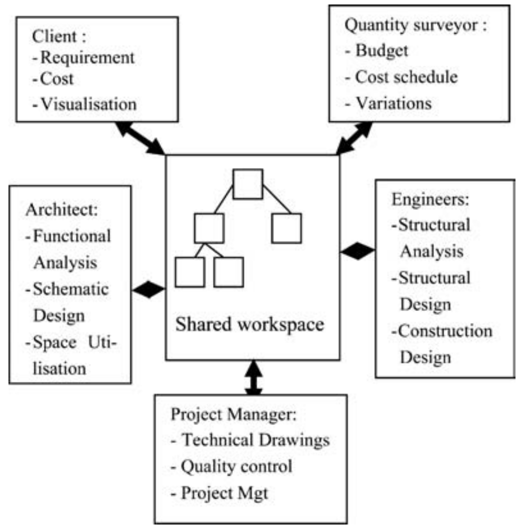

Figure 4. The modern approach to product development.

According to the NSF (National Science Foundation), the research areas that have the greatest impact in the next ten years are: techniques and tools cooperative models / innovative methods, tools/ infrastructure integration system and computer systems development aid. The research projects address different aspects of cooperative development:

1 The study of architecture: to propose an architecture that allows various stakeholders to work intelligently.
2 The aspects of representation: develop models of product required for the communication of information between different disciplines.
3 The organizational and project management: propose strategies and methodologies organization of engineering activities.
4 The management techniques constraints and negotiation: to propose solutions for the detection of conflicts between officers and their resolution.
5 The management aspects of transactions: propose solutions for effective interaction between the agents and shared space communication.
6 The design methods: the engineering techniques used by each agent.
7 The visualization techniques: to develop user interfaces and physical modeling techniques.
8 Keep the reasons for the choice (rations): keep track of the justifications for solutions generated during the design or other development activities (historical design).
9 The interface between agents (mapping data): transfer of information between different agents.
10 The communication protocols: propose ways to facilitate the movement of objects between the various applications.

6 DEVELOPED STUDIES

The overall objective of our current research is the definition of a computing environment (set of methods, models and tools) support cooperative development of the building, especially in the area of commercial management. For that our studies are at 3 levels:

- Modeling generic, standardized data and simultaneous product, process and services
- Modeling of different viewpoints in a cooperative environment
- Modeling semantic associated with data to improve data exchange.

In this context, proposing an efficient approach for modeling and communication of information in collaborative environment is fundamental.

The nature of "evolutionary" development engineering and the diversity and complexity of knowledge of engineering requires a flexible representation. In this context, the bulk of our work deals with the generic representation and exchange of knowledge related to product development, techniques of databases, artificial intelligence, web semantics, web services and the recent work on standards of product.

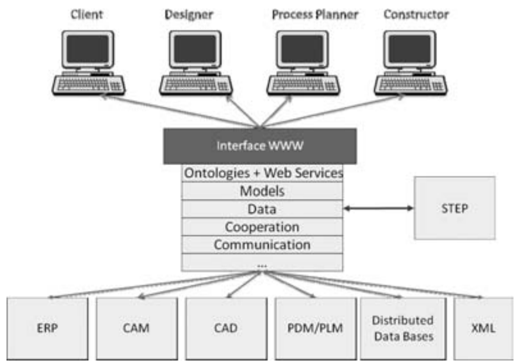

Figure 5. Proposed Cooperative Infrastructure.

In the area of representation standard product data, research works have led to international standards IFCs for the representation interpretable computer product information and their exchanges. However, if one wishes to facilitate interoperability and systems integration XAO (CAD, CAM . . .) it is no longer sufficient to represent only the data between processes, but it is also necessary to represent process and services.

Part of our work presents an original approach for modeling simultaneous and standardized product and its development process and services. This approach provides a framework for representing products, processes and services using the methodology and data models of IFCs. This facilitates the reuse of product data, processes and services for the various stakeholders in the design.

The representation of functional properties is the essential aspect of multi-views modeling and it must be considered. In this context, depending on your role in the construction project certain properties and descriptions of the product becomes more important. Each discipline should be able to represent the product with its own terminology and its own formalism. Moreover, the model of each discipline must remain linked to the models of other disciplines and can be modified to reflect changes that have been made by other designers: The models must be able to change dynamically. The IFCs offer multi-views, however these views are often not layered according to the needs of each discipline.

The implementation of this research is based on the development of a software cooperative infrastructure. This infrastructure has 3 levels, based on standard IFC, Internet + Web and data warehouse, facilitates cooperation for the modeling of different viewpoints (Figure 5).

To consider the knowledge representation aspects and represent an environment in which experts work intelligently, we are interested in studying distributed artificial intelligence techniques. The multi-agent systems in the field of distributed artificial intelligence, creates an intelligent environment by developing models of coordination and communication between disciplines, layered representation and reasoning simultaneously. Ghodous (2003) has developed a multi-agent architecture that facilitates the work of product developers and provides benefits such as modularity, efficiency, reliability and creativity.

7 FUTURE DIRECTIONS

This paper explored set out to explore the construction IT literature, in order to explore how to improve the procurement and implementation of commercial management systems in the construction industry.

It became obvious that the main body of construction IT literature has paid little attention to commercial and legal aspects of managing projects. When there are references, on several occasions the role of the QS has been questioned and dismissed. This is contrary to real-life evidence that there is a shortage of QSs in the UK and the demand for this profession is increasing, even though the role is becoming more strategic.

Many companies have had problems in implementing new commercial management systems. Here the picture is different and there is a large body of literature which the industry can learn form. In particular the literature on change management and also in software development address similar problems and can add value.

There are still many unresolved questions, which researchers need to investigate. For example:

– What does the construction industry require of a commercial management system?
– Do these requirements remain the same for each construction company or can there be a standard solution?
– Do the current commercial management systems used in large construction firms deliver their key requirements?
– How do construction companies monitor their systems effectiveness and further develop their IT systems to meet the needs of the company?
– How will commercial management systems integrate with other key construction applications, such as drawings and accounting?

This research aims to integrate the work of two research groups at Liverpool John Moores University (construction management) and Lyon University (concurrent engineering) in order to introduce commercial management into the main stream construction IT research and seek some solutions in line with other key disciplines in construction projects.

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A process model for structural identification

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ABSTRACT: Structural identification is the activity of determining how a structure is behaving using results from measurements. This paper presents a process model for carrying out structural identification over the life of the structure using results from structural health monitoring. An iterative process of measurement, evaluation, candidate model filtering and determination of subsequent measurement quantities and positions is proposed. More specifically, this process involves model sampling, error estimation and combination, model filtering, feature selection, data mining and the use of stochastic search methods. The unified modeling language (UML) is used to model interactive scenarios that are envisioned to support system identification. An example illustrates how this process model supports the iterative nature of structural management decision making.

1 INTRODUCTION

A systematic approach to interpretation of measurement data employs methodologies developed in the field of system identification (Ljung, 1999). System identification involves determining the state of a system and values of system parameters through comparisons of predicted and observed responses. Since measurements are indirect, the use of models is necessary to estimate system parameters. Model-free interpretation of data (Posenato et al., 2008), while identifying anomalies, may not accurately estimate parameters. Even though design models are the most appropriate for designing and analyzing the structure prior to construction, they often cannot be used for system identification. Models that support diagnostic activities such as data interpretation must provide accurate estimations of the real behaviour of existing structures. The current work is a combination of model-based reasoning concepts from computer science (De Kleer and Williams, 1987) and traditional model updating techniques used in engineering (Ljung, 1999).

When the forms of relationships between observable quantities and system parameters are known, regression techniques are useful for identifying system parameters. However, these techniques are rarely applicable to structural engineering because closed form relationships between system parameters and responses are often unavailable. Traditionally, structural system identification is treated as an optimization problem where differences between model predictions and measurements are minimized. Values of model parameters for which model responses best match measured data are determined by this approach. Since many model predictions might match observations with certain limits, the best matching model may not be the correct model.

Most structures are analyzed using numerical methods. Strategies that compute the values of finite element model parameters through matching predicted responses with measured values are called finite element model updating or model calibration methods. Fully instantiated models that have (continuous) values for all parameters are obtained through these procedures.

A survey of model updating procedures is given in (Robert-Nicoud et al., 2005a). Many previous studies propose methods for modifying stiffness coefficients that predict dynamic properties of structures (Friswell and Motterhead, 1995). Proposals for interpretation of static measurements are few and they involved minimizing the difference between measured and analytical quantities from a given finite element model (Liu and Chian, 1997; Reich and Park, 2001). The number of unknown variables is fixed. Models that have varying numbers of degrees of freedom and consequently, different sets of variables are not accommodated in such approaches.

Recent work has classified types of errors that can occur in system identification processes (Robert-Nicoud et al., 2005c). The presence of modelling and measurement errors (Aktan et al., 2005; Banan et al., 1994; Sanayei et al., 1997) make direct optimization unreliable. Errors may compensate each other such that the global minimum indicates models that are far away from predictions of the model of correct state of the system (Robert-Nicoud et al., 2005c).

Instead of optimizing one model, Robert-Nicoud et al. (2005a) identified a set of candidate models, such that their prediction errors lie below a threshold value. A model, according to their definition, is a distinct set of values for a set of parameters. The threshold is computed using an estimate of the upper bound of errors due to modelling assumptions as well as measurements. Ravindran et al. (Ravindran et al., 2007) later modified the approach such that the thresholds are estimated according to a desired level of identification reliability. Since the number of measurement quantities and positions required to uniquely identify all possible types of behaviour grows exponentially with the complexity of a structure, a comprehensive measurement system is rarely justifiable from the beginning of service life. Therefore an iterative process of measurement, evaluation, candidate model filtering and determination of subsequent measurement quantities and positions was proposed (Kripakaran et al., 2007c; Saitta et al., 2008).

For engineers to implement such iterative methodologies for structural management, process models that support engineer-computer interaction are vital. In the AEC/FM industry, process models are widely studied for modelling collaborative processes (Chen et al., 2005; Keller et al., 2006; Ryu and Yucesan, 2007), integrating distributed processes (Froese, 1996; O'Brien et al., 2008) and improving interoperability (Froese, 2003; Roddis et al., 2006). Such systematic approaches to infrastructure management processes are yet to be developed.

The Unified Modeling Language (UML) (OMG, 2002) models activities in a process, interactions with actors, scenarios in a process and exchange of messages. It was initially proposed for modelling software processes (Jacobson et al., 1999). It has been extended to other applications such as product life-cycle management (Thimm et al., 2006) and clinical research (Kumarapeli et al., 2007).

In this paper, a UML-based process model for system identification tasks is described. This process involves model sampling, error estimation and combination, model filtering, feature selection, data mining and the use of stochastic search methods. The objects in the system identification process are identified. A UML use-case scenario is given that illustrates the interaction between a bridge engineer and the software system supporting system identification. This scenario shows how a process model can be important for structural management decision making.

2 SYSTEM IDENTIFICATION USING MULTIPLE MODELS

In conventional system identification, a model is identified through matching measurement data with model predictions. This involves identifying values of model parameters that minimize the difference between predictions and measurements. These methods are based on the assumption that the model that best fits observations is the most reliable model. This assumption is flawed due to the following reasons: (1) system identification is an inverse problem and thus, multiple models can predict the same measurements, and (2) errors in modelling and measurement (Banan et al., 1994; Robert-Nicoud et al., 2005c; Sanayei et al., 1997) may compensate such that the model that best predicts the measurements is not the correct model. Therefore, a strategy of generation and iterative filtering of multiple models as shown in Figure 1 is necessary for identification.

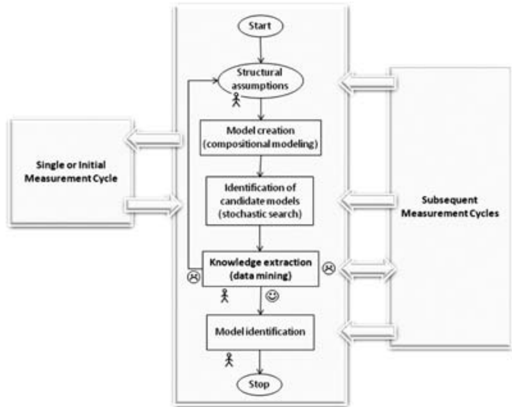

Figure 1. Flowchart showing iterative measurement- interpretation cycles.

Figure 1 shows an iterative system identification process with engineer-computer interaction required at different phases. This interaction is shown in the figure using the human icon beside the corresponding activity. Assumptions provided by engineers are used for compositional modelling and the generation of candidate model sets. For the initial measurement system design, stochastic search, which will be described later, is used to find good measurement system configurations. When measurements are available, candidate models that satisfy measurements are generated. Data mining is used to find model classes and identify parameters that have a significant influence on the structural behaviour. Engineers interpret the results to decide whether a particular from the model set is appropriate for the structure or to go for further measurements to refine the model set. In the following subsections, different aspects of this interactive process are described.

2.1 *Errors*

Errors influence the reliability of system identification. Various types of errors may compensate each other such that bad model predictions match measured values. The following definitions are used in this description: measurement error e_{meas} is the difference between real and measured quantities in a single measurement.

Modelling error e_{mod} is the difference between the prediction of a given model and that of the model that accurately represents the real behaviour. Modelling errors have three principal sources e_1, e_2 and e_3 (Raphael and Smith, 2003b). Source e_1 is the error due to the discrepancy between the behaviour of the mathematical model and that of the real structure. Source e_2 is introduced during the numerical computation of the solution of the partial differential equations representing the mathematical model. Source e_3 is the error due to the assumptions that are made during the simulation of the numerical model. Typical assumptions are related to the choice of boundary conditions and model parameters such as material properties, for example E and I. All these errors as well as the abductive aspect of the system identification task justify the use of a multiple model approach since many models may have equal validity under these conditions.

2.2 *Compositional modelling and model generation*

Figure 1 represents the framework for multiple model system identification (Robert-Nicoud et al., 2005a; Robert-Nicoud et al., 2005c; Saitta, 2008; Saitta et al., 2005). Modelling assumptions and measurements from existing measurement system are provided by engineers. Given this information, candidate model sets are generated using stochastic search. Modelling assumptions define the parameters for the identification problem. The set of model parameters may consist of quantities such as elastic constant, connection stiffness and moment of inertia. Each set of values for the model parameters corresponds to a model of the structure.

Stochastic search uses the concept of compositional modelling to sample various combinations of modelling assumptions. Compositional modelling is a framework for constructing adequate device models by composing model fragments selected from a model fragment library (Falkenhainer and Forbus, 1991). Model fragments partially describe components and physical phenomena. A complete model is created by combining a set of fragments that are compatible. For modelling the behaviour of structures, fragments represent support conditions, material properties, geometric properties, nodes, number of elements and loading. Assumptions are explicitly represented in model fragments so that the model composition module generates only valid models that are compatible with the assumptions chosen by users.

Model composition makes it possible to search for models containing varying numbers of degrees of freedom. There is no need to formulate an optimization problem in which the number of variables is fixed a-priori. Models are automatically generated by combining model fragments and are analyzed by the finite element method in order to compare their predictions with measurements.

2.3 *Initial sensor placement*

Decisions related to the choice of measurement technology, specifications of performance and positioning of measurement locations are often not based on systematic and rational methodologies. While use of engineering experience and judgment may often result in measurement systems that provide useful results, a poorly designed measurement system can waste time and money. A multiple model approach to system identification provides a systematic way to place sensors by allowing the engineer to choose locations that maximize the probability of identifying the correct behavioural model for the structure.

When installing the initial measurement system for a structure, there are no previous sets of measurements to use as basis for the design. Using engineering assumptions and damage scenarios (Kripakaran et al., 2007a), candidate model sets are generated using model composition (Robert-Nicoud et al., 2005b). Each model is evaluated by finite element analysis. Its predictions p_i at all possible sensor locations are computed and stored in a set M_0. The number N of sampled models depends upon the modelling assumptions and engineer preferences. Thus, there are N sets of predictions p in M_0.

The goal of measurement system configuration is to place sensors at locations that offer maximum separation between these N model predictions. Given a sensor configuration with s number of sensors, its performance is evaluated as follows. Depending upon the precision of the sensor and the model predictions in M_0, a suitable number of intervals I is identified for classifying predictions at each potential sensor location. At each location i where a sensor is placed, a histogram with I intervals is built for the model predictions in M_0. Each bar in the histogram represents the number of models whose predictions lie within the corresponding interval. Let B_i represent a set of subsets where each subset contains predictions in a bar of histogram at location i. Thus, $B_1, B_2 \ldots B_s$ represent the corresponding sets obtained by evaluating histograms at sensor locations 1 to s. Then the maximum number of non-identifiable models U_{max} is given as the maximum possible size of the set B given by

$$B = \{b_1 \cap b_2 \cap b_3 \ldots \cap b_s\} \quad (1)$$

b_i represents an element of set B_i. Thus the objective of the optimal sensor placement problem is to minimize the value of U_{max}.

Stochastic search (Domer et al., 2003; Raphael and Smith, 2005) has been shown to perform well for such combinatorial problems. PGSL (Raphael and Smith, 2003a) is a direct search algorithm that employs global sampling to find the minimum of a user defined objective function. Gradient calculations are not needed and no special characteristics of the objective functions (such as convexity) are required.

Primary input to PGSL is the number of variables and the range of acceptable values for each variable. For the sensor placement problem, the number of decision variables is equal to the number of potential sensor locations. The stochastic sampling nature of PGSL means that it operates only on continuous variables. However, the variables for the sensor placement problem are binary decision variables representing the presence or absence of a sensor at each sensor location. To overcome this problem, each variable is modelled as continuous and varying between 0 and 1 in PGSL. Consider the case when PGSL is used to find the optimal sensor locations for number of sensors equal to I. Then each solution generated by PGSL is interpreted as having sensors only at those locations corresponding to variables with the I largest values. Readers interested in a detailed description of the application of PGSL for sensor placement are referred to (Kripakaran et al., 2007b; Robert-Nicoud et al., 2005b; Saitta et al., 2006).

2.4 *Model identification*

Measurements generated by continuous monitoring can be used to identify candidate models that represent the behaviour of the structure. A model is defined by (Robert-Nicoud et al., 2005a) as a distinct set of values for a set of parameters. An objective function is used to decide whether a model can be classified as a candidate model. The objective function Z is defined by Equation (2).

$$Z = \begin{cases} \varepsilon, \text{ if } \varepsilon > \tau \\ 0, \text{ if } \varepsilon \le \tau \end{cases} \tag{2}$$

$$\varepsilon = \sqrt{\sum (m_i - p_i)^2} \tag{3}$$

ε is the error which is calculated as the difference between predictions p_i and measurements m_i. τ is a threshold value evaluated from measurement and modelling errors in the identification process. The set of models that have $Z = 0$ form the set of candidate models for the structure. The threshold is computed using an estimate of the upper bound of errors due to modelling assumptions (e_{mod}) as well as measurements (e_{meas}).

An important aspect of the methodology is the use of a stochastic global search for the selection of a population of candidate models. Mathematical optimization techniques that make use of derivatives and sensitivity equations are not used because search is performed among sets of model classes that contain varying numbers of parameters and multiple local minima have been observed in the search space.

2.5 *Iterative sensor placement*

Candidate models are analyzed using data mining techniques such as feature selection and clustering for finding model classes and identifying parameters that have significantly influence structural behaviour (Kripakaran et al., 2007c; Saitta et al., 2008; Saitta et al., 2005).

The set of candidate models is iteratively filtered using subsequent measurements for system identification. The location that gives the maximum dispersion among model predictions is chosen for subsequent measurement. The notion of entropy is used to measure the separation between predictions. The expression used to calculate entropy is the Shannon's entropy function (Robert-Nicoud et al., 2005b; Shannon and Weaver, 1949) which has been used for decades in the field of information theory. Shannon's entropy function represents the disorder within a set. In the present work, a set is an ensemble of predictions for a particular system identification task. The best measurement location is the one with maximum entropy (model predictions have maximum variations). For a random variable X, the entropy $H(X)$ is given by Equation (4).

$$H(X) = -\sum_{i=1}^{|X|} P_i \cdot log(P_i) \tag{4}$$

P_i are the probabilities of the $|X|$ different possible values of X. For practical purposes, (0.log(0)) is taken to be zero. When a variable takes $|X|$ discrete values, the entropy is maximum when all values have the same probability $1/|X|$. Thus entropy is a measure of homogeneity in a distribution. A completely homogeneous distribution has maximum entropy.

In the present study, the entropy for a given sensor location is calculated from the histogram of predictions. At each possible sensor location, a histogram containing predictions is built. Each bar in the histogram represents those models whose predictions lie within that interval. Iteration involves incrementally locating the sensor position that corresponds to the maximum entropy of predictions.

3 PROCESS MODELS FOR SYSTEM IDENTIFICATION

UML is a modelling language that was originally devised to enable the development of robust and easy-to-maintain enterprise-level software systems. However, today it is used in a variety of applications such

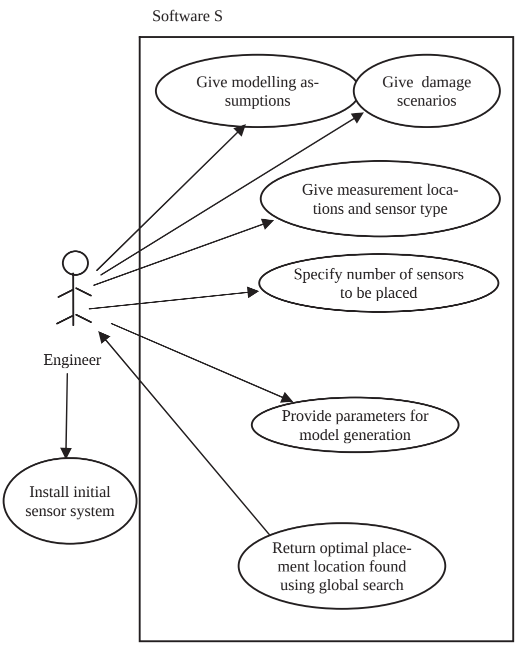

Figure 2. UML use case diagram for designing initial measurement system.

as business process management and product lifecycle management. In this paper, preliminary research into using UML for modelling processes in system identification is presented.

Use case diagrams for two important scenarios – (1) initial measurement system design and (2) iterative sensor placement, are proposed in this paper. To develop use case diagrams, the actors in the scenario have to be first identified. In this case, the actors are the engineer and the software system *S* that supports system identification.

3.1 *Sensor placement scenarios*

A UML use case diagram for designing the initial measurement system for a structure is given in Figure 2. It shows the activities that engineers would pursue while designing the initial measurement system. The arrows indicate the direction of flow of data. The ovals indicate the activities involved in this phase. Similarly, Figure 3 shows the use case diagram during iterative sensor placement.

Use case diagrams give only a general perspective on the activities in a particular scenario. It does not provide a chronological sequence of activities. Sequence diagrams for specific scenarios are created so that the software is designed to perform well under these situations. Figure 4 shows a UML sequence diagram that illustrates a scenario where the engineer designs the initial measurement system by iteratively changing the number of sensors and sensor types. A similar UML sequence diagram for the case where the engineer finds locations for subsequent measurement is shown in Figure 5.

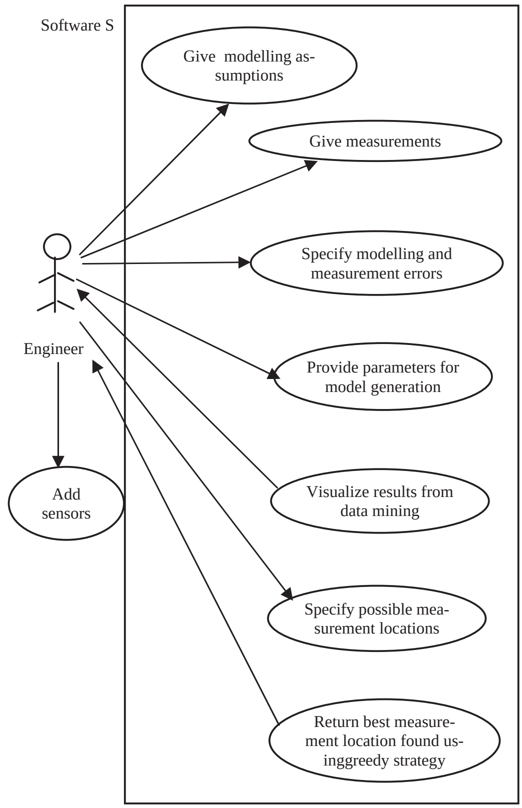

Figure 3. UML use case diagram for deciding subsequent measurement locations.

4 DISCUSSION

Both use-case diagrams do not completely reflect all complexities in all phases of structural management. For example, during initial measurement system design, engineers are likely to find optimal solutions involving different types of sensors and different numbers of sensor locations. Engineers may vary modelling assumptions to see how the optimal measurement systems change. Moreover, it is seldom feasible to test all possible models. Engineers would limit the model generation process to cover only a certain part of the model space by specifying appropriate parameters. To study the robustness of the process, engineers may look at solutions using different initial parameters. However, these diagrams are useful to

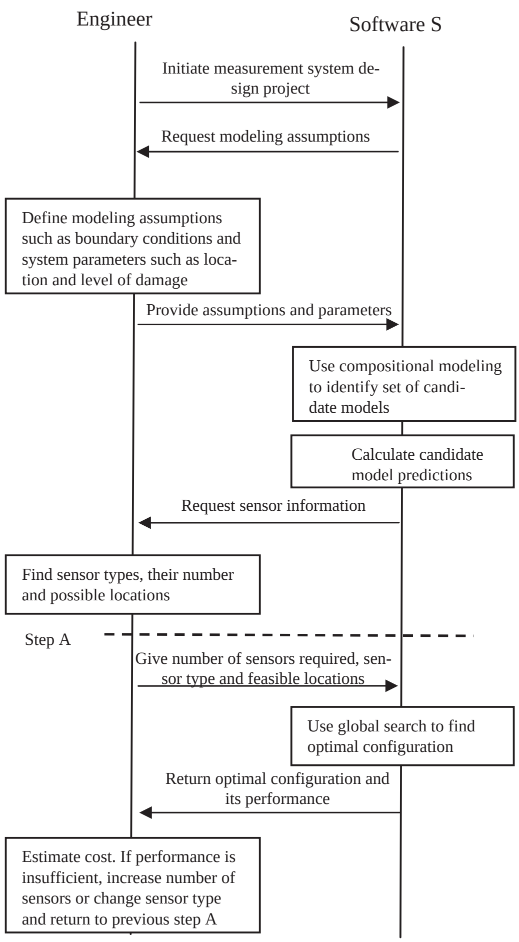

Figure 4. UML sequence diagram showing information flow and activities during initial measurement system design.

obtain a general overview of the different scenarios under which engineers may interact with the software system for structural management.

Figures 2, 3, 4 and 5 also show that software for structural management have to be designed to support effective engineer-computer interaction. Different kinds of input are required from engineers at different stages. Results from sophisticated algorithms are displayed to engineers. For instance, results from data mining techniques can be difficult to understand. Recent research has resulted in visualization methods based on principal component analysis (Saitta et al., 2008) for displaying multi-dimensional data.

During iterative measurement-interpretation cycles, engineers use subsequent measurements for model filtering. Management systems have to be designed to visualize model classes that were eliminated by the new measurement. The most difficult decision for

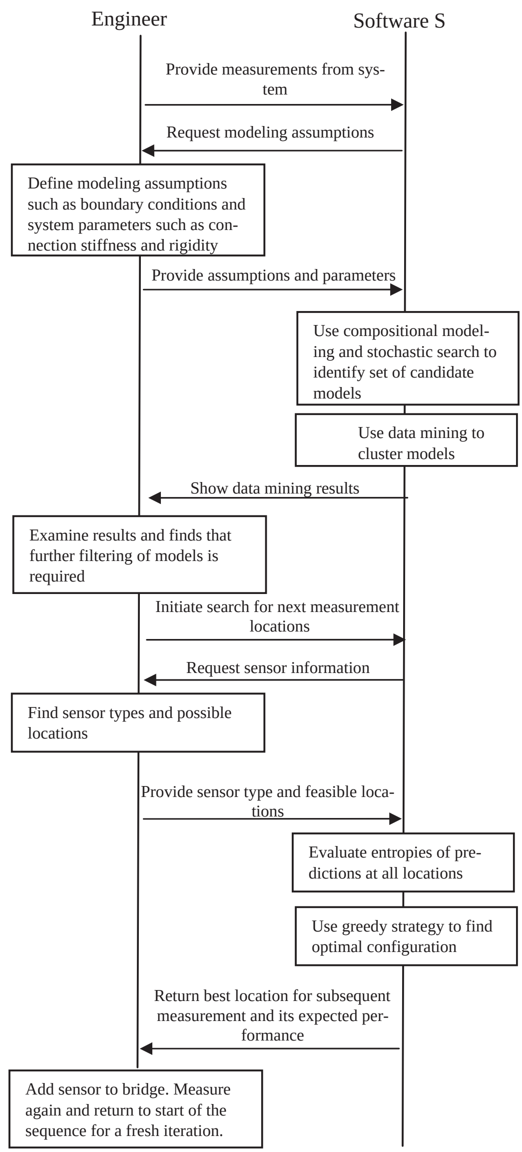

Figure 5. UML sequence diagram showing iterations during iterative measurement-interpretation cycles.

engineers may be to decide if further measurement is warranted. The entropies among model predictions are helpful to engineers. If the entropies are very small, then further measurements are unlikely to eliminate any model. However, engineers may suggest new measurement locations and other sensor types to enhance the identification process.

Another important aspect to note from Figures 4 and 5 is that the computing techniques vary dependent on the purpose of measurement system design.

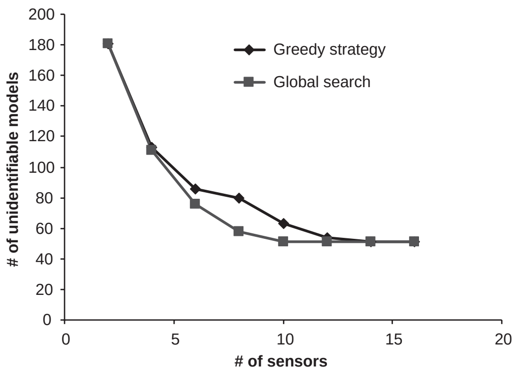

Figure 6. Comparison for global search and greedy strategy for initial measurement system design (from (Kripakaran et al., 2007b)).

When the initial measurement system is designed for a structure, global search is a better algorithm for finding the optimal measurement system configuration. Figure 6 shows the results from a comparison between global search and greedy strategy for initial measurement system design (Kripakaran et al., 2007b). The figure shows that global search reduces the set of unidentifiable models faster than greedy strategy. While greedy strategy suggests 14 sensors for the initial measurement system, global search provides a solution with only 10 sensors for the same performance. However, greedy strategy plays an important role during measurement-interpretation cycles to identify locations for subsequent measurement that are likely to filter the maximum number of models from the current model set.

5 CONCLUSIONS

The following conclusions come out of this paper.

- Structural identification using iterative measurement-interpretation cycles is an interactive process that requires the knowledge and the judgment of the bridge engineer.
- UML-based process models are important for designing effective software systems that support such interactive system identification.
- The most appropriate sensor placement algorithms are global search for the initial measurement cycle and greedy search for subsequent measurement cycles.

Future work will focus on using UML-based process models for effective engineer-computer interaction. Research into visualization and management of model spaces is also anticipated.

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A trust-based dashboard to manage building construction activity

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ABSTRACT: Coordination of construction activities is essential to ensure the quality of built works, the respect of delays or the interactions between heterogeneous actors involved in an AEC project. The coordination activity has become a contractual task in numerous countries and specialized actors have emerged. Their work is largely based on their experience and their skills to analyze building situations and to anticipate the dysfunctions that could happen. In this article we address the issue of trust and its potential role in coordination of AEC construction projects. Then, we suggest a methodology enabling the identification of trust indicator in the good progress of the activity. Our final proposal consists of a dashboard tool for construction manager integrating the concept of trust.

1 INTRODUCTION

The AEC sector is characterized by a particular production mode (Chemillier 2003). It is different from other industrial sectors because construction relies on a unique order, which leads to the execution of a prototype. Moreover, the team is constituted for the duration of the project and this is the source of difficulties to create and maintain durable relationships between actors. At last, construction activity is situated. It is performed on the building site and consequently the way of proceeding has to be adapted to the specificities of the terrain.

In the framework of this article, we will particularly focus on the execution stage. The building site is subjected to different hazards. Tahon (Tahon 1997) highlights the following dyfunctions:

- Dysfunctions linked to the environment (e.g. weather, and nature of the sol),
- Dysfunctions linked to the stakeholders (e.g. lack of trust),
- Dysfunctions linked to the documents (e.g. problems of updates),
- Dysfunctions linked to the building elements and their execution (e.g. difficulty of execution, problems related to the interfaces).

In such a context and because of the growing complexity of the construction projects and the will of increasing quality, new actors appear in the team of project (e.g. quantity surveyor, project manager...). We will centre here on the activity of the construction manager. His role consists in advising the owner throughout the project life cycle about the cost, the schedule, and the quality of executed building elements. In order to carry out the different aspects of his mission, diverse tools are at the disposal of the construction manager. We can distinguish them in two categories: current tools and emergent tools. Among the frequently used tools, we can cite the Gantt and Pert scheduling methods, or some tools such as word processors allowing writing the building site meeting report synthesizing the points of dysfunction and the taken decisions. We can also identify some other tools used more rarely. Among these, we can mention document management platforms, 4D simulation tools (Chau et al. 2005; Sadeghpour et al. 2004), putting into relation a 3D modelling of a building and its planning and performance evaluation system (Arslan et al. 2008), allowing the evaluation of the actor's performance. However, these tools offer only a partial vision of the cooperation context. Therefore, we suggest that a dashboard, which would synthesize data

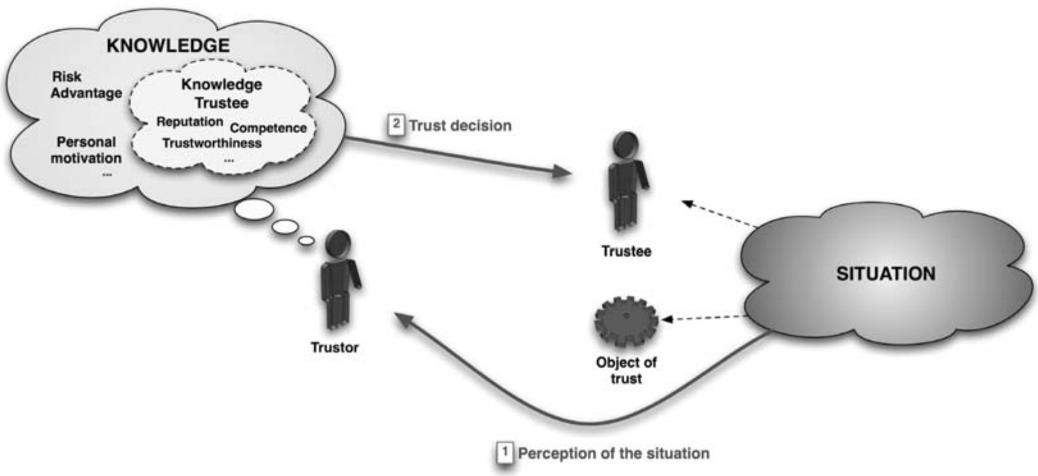

Figure 1. Concepts related to trust in situated action.

coming from these different views, could constitute a good decision support system. Moreover, we make the hypothesis that the uncertainty linked to the environment of the building construction activity makes way for the notion of trust. Thus, we propose a dashboard based on the representation of trust to support coordination of building construction activity. In this article, we will first examine the notions of trust and context in the AEC sector. Then we will identify trust indicators for managing the building construction activity and how to measure them.

Finally, we will focus on our proposal of a dashboard based on trust, and more precisely on its modelling and on its implementation.

2 TRUST AND CONTEXT IN AEC

2.1 *Theoretical approach of trust*

Trust is a notion which is the object of diverse points of view in literature. Stephen Marsh (Marsh 1994) identifies two essential reasons that allows justifying that. Firstly, we are all experts of trust because it is inherent in our society, in our day-to-day. Moreover, when scholars study the question of trust, their works are situated in a particular domain (e.g. economy, politics. . .). We can therefore notice a lot of definitions sometimes divergent. The second reason makes reference to the intrinsic characteristics of trust. If there is different viewpoints about trust, this is simply because it can take diverse forms (Rousseau et al. 1998). Trust can be associated to a person's behaviour (Deutsch 1962), to a device for reducing the social complexity (Luhmann 1988), or to a rational choice (Orlean 1994).

Our analysis of trust let us to identify trust as a relationship between a Trustor (The person who trusts) and a Trustee (The person who receives trust). This relationship is inserted in a situation where the Trustor can formulate positive expectations about the Trustee's behaviour. When the Trustor makes choice of trust, he thinks that he can anticipatively assess the Trustee's behaviour even if he is conscious that he takes risks if trust is not honoured. We retain that trust relationship is established in two sequences (see figure 1):

- *The perception of the situation* constitutes an essential stage because it allows the Trustor to determine if he think that the Trustee is trustworthy to lead positively the object of trust. This perception takes into account the contextual aspects linked to the Trustee and to the object of trust. It is directly linked to the knowledge available for the Trustor in order to evaluate the perceived trustworthiness in this particular context. Among this knowledge, we can dissociate the knowledge related to the object of trust such as risk, advantage, the motivation of the Trustor. . . and the knowledge concerning the Trustee such as his competence, his trusthworthiness, his integrity, his benevolence (Mayer et al. 1995). . . We highlight that the notion of perception of the situation can be associated to a subjective analysis established in this case by the Trustor. Moreover the anterior experiences with the Trustee will contribute to refine the knowledge about him and to adjust the perceived trustworthiness.
- The *decision of trust* aims to act on trust. When the Trustor acts on trust, he becomes vulnerable because he delegates the object of trust (i.e. an activity). It is necessary to precise that trust overpasses the economic rationality. Indeed, when the Trustor makes this choice, he is conscious that he takes a risk. More precisely, in a case where

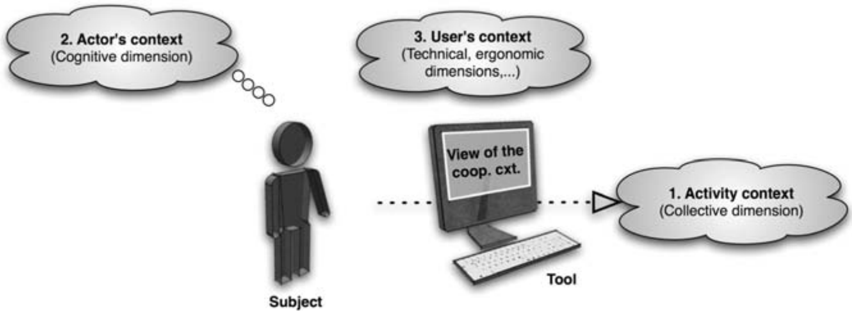

Figure 2. Three contexts of action.

trust would not be honored, consequences could overpass the gain if trust was respected.

Finally, it is important to point out that even if we have principally mention interpersonal trust considering that the Trustee is a person, the notion of trust relationship can be extended to an organization, an artifact, a product, information, or data (Sutcliffe 2006).

2.2 *Trust and context*

The decision of trust relies on the perception of the context at a given moment. Indeed, we do not absolutely trust an actor but we trust somebody in the framework of a particular activity (Cook et al. 2005). Furthermore the proximity between the notion of trust and the notion of risk highlights this context dependence because risk cannot be envisaged apart from a given situation (Mayer et al. 1995

2.2.1 *Three contexts of the activity*

Our study of the cooperative activity allowed us to highlight three different types of contexts (Kubicki 2006): the cooperation context, the actor's context and the user's context. Figure 2 illustrates these contexts.

The **cooperation context** (See Fig. 2, [1]) describes the collective dimension of the activity. The generic elements constituting each cooperation context are the following ones:

- The *actor*. This concept refers to a human resource included in an organization and taking part in the execution of the activity.
- The *activity*. It is decomposed and structured. Its execution constitutes a common goal for the actors.
- The *document*. This concept refers to "definitive" or "intermediate" results of the activity. Documents are required to perform building elements.
- The *building element*. This concept results also from the activity. Its execution concretizes the common goal of the actors.

The **actor's context** (See Fig. 2, [2]) refers to the knowledge manipulated by the actor and to the cognitive processes, which he carries out in preparation for his individual action. Knowledge mobilization and treatment mechanisms are intimately linked to the actor's business competences and to their point of view on the cooperative activity.

Finally, the **user's context** (See Fig. 2, [3]) is situated between the cooperation context and the actor's context. It considers the actor as a user of computing tools. Such tools consist of supports for the perception of the cooperative activity context. Taking this context into account is essential when we try to design activity support tools. Indeed, this context allows us to consider the tool as a mediator between the actor and the activity. It highlights the fact that a tool must not only take into account the collective activity but also adapt itself to its user.

2.2.2 *Trust in the AEC context*

Our approach of trust considers that trust decision is linked to a cognitive process that allows the actor to identify the perceived trustworthiness. Such as (Mayer et al. 1995), we think that trust can guide action. We suggest also that a good perception of the context can be important to adapt trust decision and adjust the actor's action on the cooperation context. In the AEC sector, trust is a central question: trust in the good progression of the collective activity, trust in the achievement of the expected results, trust in human resources... Concretely, trust in AEC concerns each aspects of the cooperative activity. In our works, we focus on "trust in the good progression of the activity" and we consider that it relies on the following aspects: the progress of the task under consideration, the actors responsible for executing the task and their performance, the building element resulting from the task, and the documents required for performing the task.

The figure 3 allows us to summarize the fundamental aspects of our approach:

- The **cooperation context**. It is an information source mediated by the tools and perceived by the actor.

– The **actor's context**. It refers to the actor's knowledge, only a part of which is proceduralized in preparation for action. Moreover, this knowledge allows the actor to determine the trust in the good progression of the activity and consequently, to adjust his action on the cooperation context.
– **Trust**. It refers to trust in each aspects of the cooperation context (i.e. activity and its progression, document, building element and actor's performance).
– The **user's context**. It is mediated by the tool and allows the user to obtain a contextual visualization adapted to him.
– The **perception of the cooperation context**. It is guided by the tools and the actors' business skills.
– The **action on the cooperation context**. It refers to an action adapted to its context and guided by the trust perception in each aspect of the cooperation context (Progression of the task, actors, building elements and documents).
– The **capitalization**. It is essential in the concept of trust, because trust is built on the basis of previous experiences.

3 TRUST INDICATORS FOR THE AEC SECTOR AND MEASURE

3.1 *Identification of trust indicators*

We have identified a close relationship between the concepts of trust and risk. In fact trust is conditioned by the perceived risk. We have taken inspiration from the studies about risk in AEC (Boone 2007; Klemetti 2006; Zou et al. 2007) to determine our trust criteria but our approach remains completely different. In fact, a risk management process comprises specific stages: identification of risks, assessment of the risk exposure, assessment of the risk acceptance and action choice (Alquier & Tignol 2007). We rather try to identify the elements allowing the construction manager to trust the task under consideration. Our objective is not to provide him a detailed analysis of risk exposure but instead to make use of his usual views (e.g. planning) in order to extract trust indicators in the good progression of the activity. So, our approach aims to assist the coordination through the perception of the activity context based on the interpretation of trust indicators.

We suggest categorizing the criteria in function of four aspects specific to the construction task which will determine trust: its progress, the actors in charge of the execution, the building elements resulting from the task, and the documents required for the execution of the task. Brainstorming helped us to firstly define these criteria. Then, we compared the results with criteria generally defined in risk studies. Finally, we made a survey on the basis of a questionnaire (distributed to architects, engineers, contractors) in order to validate and refine the criteria.

Table 1 summarizes the trust criteria related to the four aspects of the activity and for each of them we indicate their potential source:

– *Task progress-Specific Trust* is influenced by the state of the task (in hold, in progress, in advance, delayed), the problems related to execution (identified during the construction site visit), and the weather forecast.
– *Actor-Specific Trust* is influenced by his skills (e.g. certification level), its performance (e.g. on previous construction sites and/or on the current one), and his attendance at construction team meetings.
– *Document-Specific Trust* depends on their state but also on the state of the requests associated to the documents (e.g. validation), and on their availability on the building site.
– *Building element Specific Trust* is influenced by the level of difficulty of the execution, the potential modifications in comparison with initial technical description and the coherence with provisional budget.

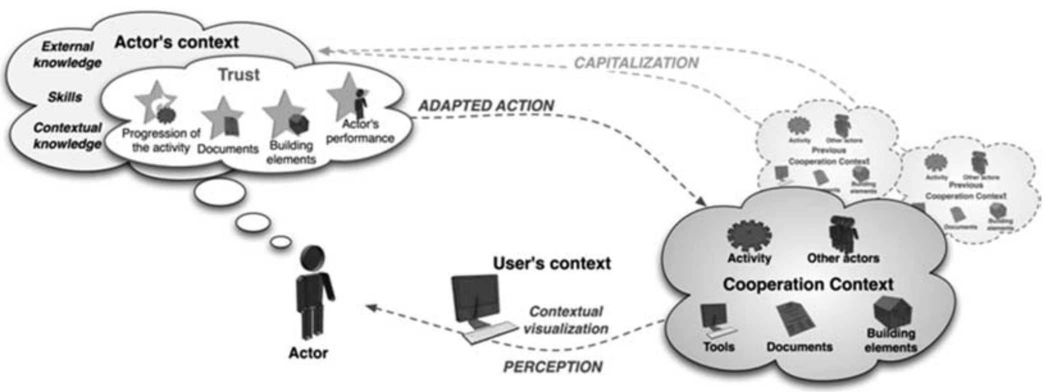

Figure 3. Trust and context.

3.2 *Measure of trust indicators*

To evaluate the level of trust in the good progression of an activity, we have adapted S.P. Marsh's approach (Marsh 1994), who identifies the trust during cooperation and we adapt it to our specific context of cooperation.

We distinguish two levels of trust indicators: the Global Trust and the Specific Trust.

The Global Trust characterizes the trust in the good progression of the activity in a particular situation. The Specific Trust corresponds to each aspects of the task. We distinguish four types of Specific Trust in a particular situation:

– Task progress-Specific Trust,
– Actor-Specific Trust,
– Document-Specific Trust,
– Building Element-Specific Trust.

The Figure 4 illustrates our approach related to the Global Trust and the Specific Trust.

For measuring Global Trust in the good progression of an activity, we make use of the formula below (the Table 2 summarizes the notions):

$$T(\alpha) = \frac{T_{tp}(\alpha)I_{tp}(\alpha) + T_a(\alpha)I_a(\alpha) + T_d(\alpha)I_d(\alpha) + T_{be}(\alpha)I_{be}(\alpha)}{I_{tp}(\alpha) + I_a(\alpha) + I_d(\alpha) + I_{be}(\alpha)}$$

Thus, the Global Trust results from the trust in each aspects of the task (Progression of the task under consideration, actors in charge of its execution, required documents, performed building elements)

Table 1. Criteria and information sources for trust indicators.

Criteria	Information sources
(1) Task Progress- Specific Trust Indicator (TP-STI)	
State of the task	Gantt Planning, Pert Planning, 4D
Problems of execution	Meeting report
Environment	Weather forecast,. . .
(2) Actor-Specific Trust Indicator (A-STI)	
Competence	Certification (ISO, Qualibat[1])
Performance	Performance evaluation system
Attending construction site meeting	Meeting report
(3) Document-Specific Trust Indicator (D-STI)	
State of the documents	List of document
State of request	Documents transmission list
Availability on the building site	List of documents
(4) Building Element-Specific Trust (BE-STI)	
Level of difficulty of execution	Technical report[2]
Modifications	List of modifications
Respect of budget	Budget monitoring

[1]Qualibat: French organism in charge of qualification and certification of French construction firms, http://www.qualibat.com/)
[2]We make reference here to the «Unified Technical Documents» (DTU), which are standard norms in the French construction sector

Table 2. Global Trust – Summary of annotations.

Description	Representation	Value range
Activity	α	
Global Trust	$T(\alpha)$	$[-1, 1]$
Specific Trust	$T_x(\alpha) \quad x \in \{tp, a, d, be\}$	$[-1, 1]$
Importance	$I_x(\alpha) \quad x \in \{tp, a, d, be\}$	[0,1]

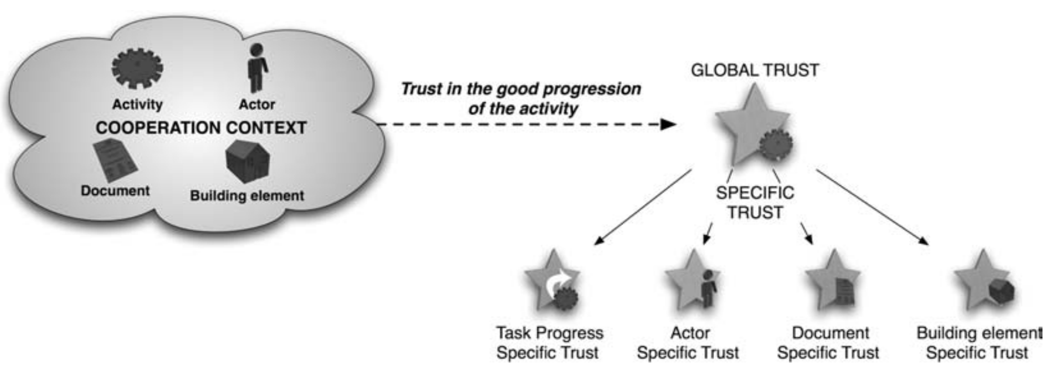

Figure 4. Global and specific trust.

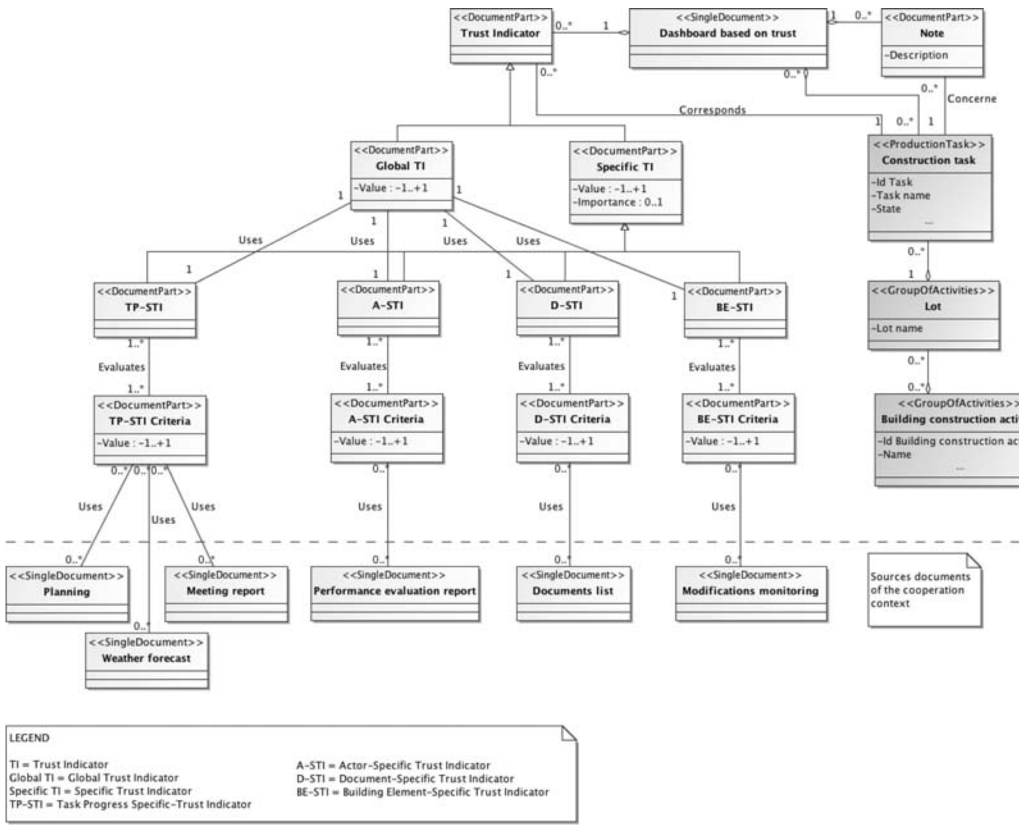

Figure 5. Data Model of the Coordination Dashboard interface.

and is balanced according to the importance,[1] which is valuated by the building construction manager.

Then, for assessing each type of Specific Trust, we make use of the criteria identified in section 3.1. We consider the value of each criterion and we judge if it is positive or negative for the good progress of the task (see (Guerriero et al. 2008) for more information).

4 BAT'ITRUST, A TRUST-BASED DASHBOARD

In this section we present our proposal of a dashboard tool, based on the concept of trust. We will describe firstly the specifications of the dashboard visualization itself, relying on a model approach developed in the CRAI laboratory. Then we will present the Bat'iTrust prototype integrating the dashboard in a multi-view interface.

[1] According to S.P. Marsh, "importance is an agent-centred or subjective judgement of a situation on the part of the agent concerned".

4.1 *Modelling the trust-based dashboard view*

Past works carried out at the CRAI laboratory led us to develop a model driven approach. It aims to describe the cooperative context of AEC projects and the related views used in cooperation-support tools. We have based our work on this approach and we have specified the dashboard view through a model of its concepts.

We have defined the model of the concepts of Bat'iTrust view. It has been integrated in our model framework (Kubicki et al. 2007). Figure 5 represents this model of concepts of the dashboard, and their relationships with the information sources necessary to the measure of the indicators (see Table 1). We can distinguish the following concepts of the model:

- **Global Trust Indicator** (Global TI) identifies a global trust indicator for the task under consideration.
- **Specific Trust Indicator** (Specific TI) regroups the following diverse types:
- *Task Progress-Specific Trust Indicator* (TP-STI) identifies if there are some dysfunctions concerning

the progress of the activity by evaluating the TP-ST criteria, which make use of information contained in the planning, the meeting reports and the weather forecast.
– *Actor-Specific Trust Indicator* (A-STI) identifies if there are some dysfunctions concerning actors by evaluating A-ST criteria, which refers to information contained in the performance evaluation, and meeting reports.
– *Document-Specific Trust Indicator* (D-STI) identifies if there are some dysfunctions related to documents by evaluating D-ST criteria, which refers to the list of documents and the list of documents requests.

Building Element-Specific Trust Indicator (BE-STI) identifies if there are some dysfunctions related to building elements by evaluating BE-ST criteria, which refers to the budget monitoring and the list of modifications. This list brings together the differences in comparison with what was expected in specifications and in the forward-looking budget.

Finally, we insist on the fact that all information required for measuring theses different types of Trust Indicators are included in source documents of the cooperation context.

4.2 *The Bat'iTrust prototype*

4.2.1 *Functionalities description*

Bat'iTrust prototype relies on previous works made during the development of a first application called Bat'iViews (Kubicki et al. 2007).

The issue addressed in this previous project was that the views used everyday by the construction actors (e.g. planning, meeting report...) provide only fragmented representations of the cooperation context. Then, the proposal consisted in making explicit the relationships between these views. Bat'iViews integrates the following views: planning, meeting report, 3D mock-up and remarks list in a multi-view interface. It provides navigation through interactions between the views. For example, when a remark is selected in the meeting report, Bat'iViews highlights the related objects in the 3D mock-up and the related tasks in the planning. The navigation is called a free navigation. It means that the user can indifferently select an element in one of the views and the tool highlights the related elements in the other views.

Our proposal of a dashboard based on trust is integrated in the continuity of these works. We suggest inserting a new view "Dashboard based on trust" in the multi-view interface in order to guide the navigation of the user (in our case a construction manager).

The objectives of Bat'iTrust are:

– To provide a synthetic view to the construction manager. This would allow him to judge the state of the construction activity at a precise time, on the basis of trust indicators.
– To provide adapted configurations of views helping him to understand the potential dysfunctions.

The dashboard displays a list of construction tasks and provides for each of them a state (in progress, in hold...), a global trust indicator and specific trust indicators (TP-STI, A-STI, BE-STI, D-STI). These indicators would help the construction manager to identify quickly the tasks where a risk of potential dysfunction exists.

Moreover, the selection of a specific trust indicator by the user provides a view arrangement adapted to his analytic needs:

– The *Task-Progress Specific Trust Indicator* is associated to a configuration of views composed of the planning view, remarks list view, and the 3D mock-up view.
– The *Actor-Specific Trust Indicator* is associated to configuration of views composed of performance evaluation view and a graph representing the context of the actor.
– The *Building Element-Specific Trust Indicator* is associated to a configuration of views composed of the 3D mock-up view, the building technical specification view, the budget monitoring view and the modifications follow-up view.
– The *Document-Specific Trust Indicator* is associated to a configuration of views composed of the document management view, the document-related request monitoring view and the document-related reactions follow-up view.

Finally, while the user is navigating in Bat'iTrust and identifying potential problems, he can associate personal notes to the task under consideration in order to keep trace of his reasoning. If we consider the example illustrated in figure 6, the construction manager selects the task progression indicator of the task «Shaft column groundwork» and he can see an adapted configuration of views composed of: a «remarks of the meeting report» view that displays remarks related to the task under consideration, a «3D mock-up» view that highlights the building elements related to the task and finally, a "planning" view that highlights the task in a Gantt planning.

4.2.2 *Prototype implementation*

Bat'iTrust prototype is a Rich Internet Application (RIA) developed in Flex and accessible with a Web browser. It is based on the MVC (Model, View Controller) architecture enabling the clear distinction between three parts of the application:

– The data model (Model),
– The representation of the data in the user interface (View),
– The interactions (Controller).

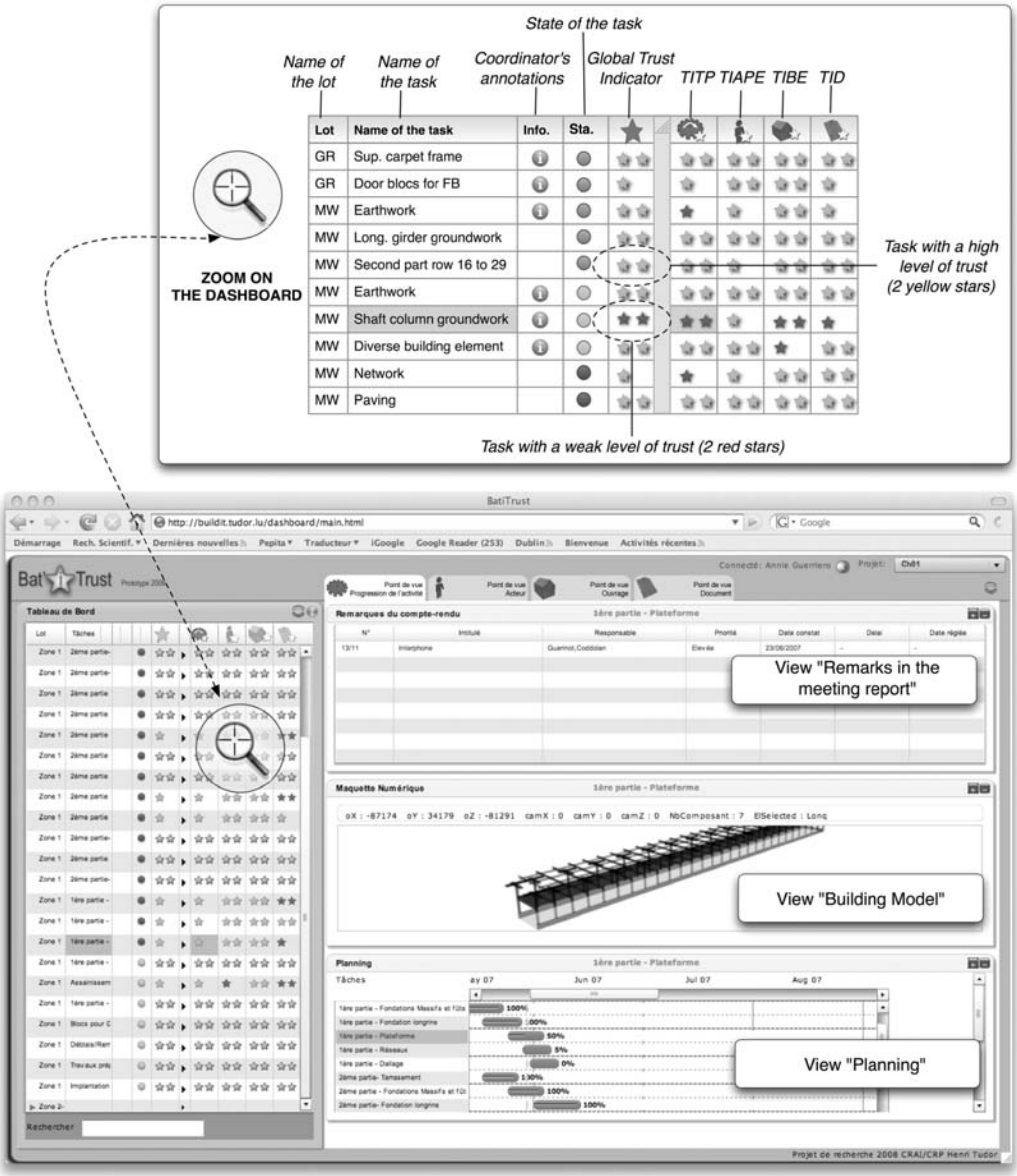

Figure 6. Bat'iTrust view and detail of the dashboard based on trust.

This classical approach enables a clear distinction between data, representation and user-interaction. It fits our needs to treat dynamic data coming from heterogeneous sources (documents, tools).

In this first implementation stage data used in Bat'iTrust are described in separate XML files, created manually. In the future we expect the content of the different views to be automatically generated by the implementation of REST Web services, linked to the cooperation context.

The figure 7 illustrates interaction principles between the "Dashboard" view and the "Remarks in the meeting report" view. Web services interrogate the database of the cooperation context in order to feed the content of the views (e.g. Web services for measure of the diverse trust criteria). Then, the selection of an indicator in the view 1 Dashboard triggers the event "Filter Remarks" [1]. The event is caught by the controller [2]. The controller calls the command associated to the event [3]. The command makes relationships between

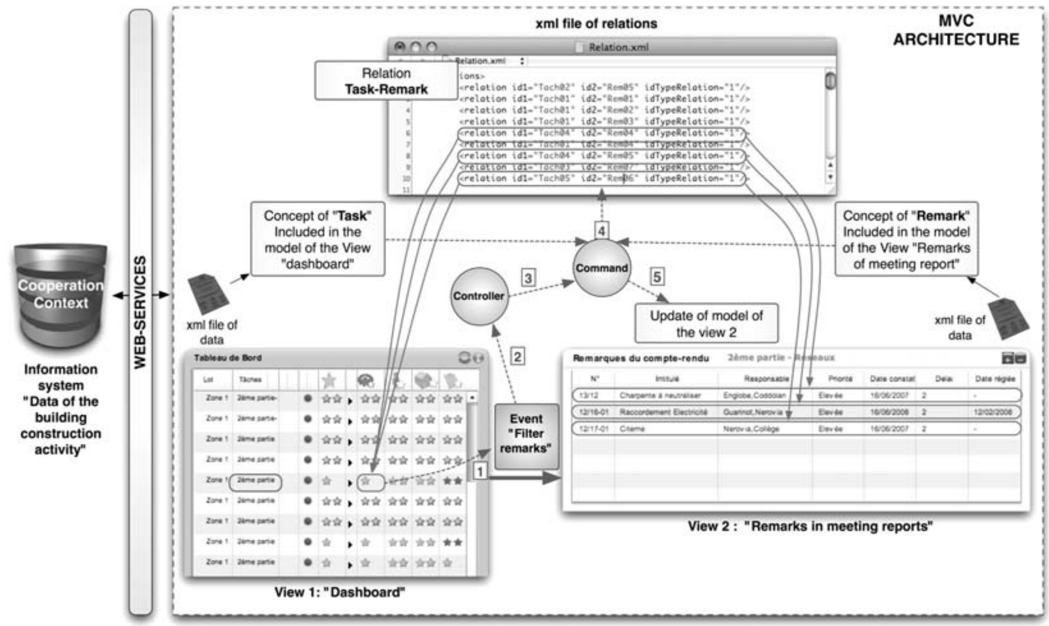

Figure 7. Interaction between views in Bat'iTrust prototype.

the dominant concepts of the two views (the concept of "Task" for the view Dashboard and the concept of "Remark" for the view "Remarks in the meeting report") [4]. And finally, the model of the view is updated and the view displays the selection of the remarks corresponding to the task under consideration.

5 PERSPECTIVES AND CONCLUSION

In this article we have shown that trust is an interesting concept for coordination of collective activities in AEC. Trust can guide actor to adapt his action on the cooperation context. Our proposal focuses then on trust in the good progression of the activity and considers its different aspects: specific trust in the progression of the activity, in the actors, in the building elements and in the documents. Our works lead to Bat'iTrust prototype, which comprises a dashboard view based on trust and includes it in a multi-views interface intended for managing the building construction activity.

At this stage of our research works, we are starting experiments of the prototype with users coming from the AEC sector. This stage will allow us to validate our proposal and to identify its limits. One of the limits is related to the availability of information enabling the measure of trust indicators. Coordination-related information is traditionally dispersed between various views and documents, but our proposal is built on the data model available in the CRTI-weB[2] support tools developed in Luxembourg. We have now to extend the panel of Web services required for calculating the diverse trust criteria and trust indicators.

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ICT based modeling supporting instrumentation for steering design processes

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ABSTRACT: This paper tackles the strong demand for design steering aiming at improving the quality of design and thus reducing the appearance of dysfunctions. With regard to this, we highlight the multidisciplinary characteristics as well as the predictive and reactive aspects of design steering in architecture. Then, based on existing models, we propose a model combining three primary activities (analysis, proposition, and evaluation). Then we enrich the model so that it covers the predictive and reactive aspects of design steering. This is done on the basis of our analysis of design steering, which allowed to uncover two narrowly linked but generally implicit entities: the concern situation and the aimed situation. Finally, we specify and present the mock-up of a tool that can be qualified as "reactive". This means that instead of allowing to define a solution, it allows to determine when the intervention pilot actor is needed.

1 INTRODUCTION

Nowadays, numerous architecture projects require different actors who are more and more remotely located and work together on the elaboration of a common project. The inputs of these actors of design need to be integrated by taking into account the lifecycle of the building: the particular interest is thus given to a "transversal" dimension of the design. This can be achieved by including, in the early stages of process, constraints and parameters that are usually managed much later in traditional organizations (Kusiak 1993), (Alting 1993).

This evolution of the design and the need of a complementary vision from the actors of different professions lead to the necessity of new interface activities and to the *steering of the architecture design*. In fact, depending on the different cost and quality constraints, numerous tools exist in order to "instrument" the project management (e.g. Gantt Diagram, project management portals, Computer Supported Cooperative Work, etc.). However, the implementation of this activity aiming to support the design is still poorly instrumented by tools and methods. This lack of instrumentation is typical to all the stages of the design process, and particularly to the steering activities.

In front of this situation, many works have been undertaken in order to assist the steering activity, as well as multiple tools automating its different facets have been developed (e.g. HyperArchi, e-Project, Fast-Track, Schedule, Primavera, Prosys Online, Active3D, etc). However, even with an undoubted progress in the instrumentation of steering activity, the real offer of such tools is mostly oriented towards the optimisation of the economic aspects of this activity. They help the actors to easily deal with financial, time and resources constraints of the design process. Nevertheless, the goal of automation of the design in architecture is still unachieved when we tackle cognitive aspects and process coordination of the design activity. Two complementary facets of the same activity, these two aspects can not be dissociated in an efficiency modelling of the building design process.

However, there are no tools that would assist the steering of design processes in order to ensure the coherence and the coexistence carried by the different actors of the process. For this reason, our research aims at taking into account all aspects of the organisation and the orientation of a designed building, as well as the actual state of its design. The objective is to provide a tool for design steering that will make it possible to support and collect all actors' viewpoints, and to interpret them in terms of a designed building and integrate them into the design process.

The paper is organized as follows. In section 2 we highlight the multidisciplinary characteristics as well as the predictive and reactive aspects of design steering in architecture. In section 3 we focus on establishing relations between cognitive and coordination aspects of the architecture design process (Conan, 1990). This allows us to propose a steering driven-model for design process that enables expressing different situations of the building design process. In section 4, we present a first approach of instrumentation of design processes steering in architecture.

2 THE STEERING OF ARCHITECTURE DESIGN

2.1 *A cross-field activity*

The steering of a design project in architecture consists in conducting the set of activities and processes that are necessary for the implementation and achievement of the building. Observation of practices showed us that both the building to design and the design process are concerned by this activity. We thus identify four main skill-related challenges: (i) to maintain the coherence of the building throughout its evolution (coherence between the building and the need for conception, coherence between the different components of the building); (ii) to take decisions that aim to orient the process and validate the evolutions of the building; (iii) to integrate the points of view of the different actors. (This is completed on one hand by analyzing how the specific knowledge of each actor contributes to the global vision of the building, and on the other hand by translating the different points of view into specifications for the building); and (iv) to organize the cooperation by managing the network of actors and skills in the light of the objectives and by keeping the convergence in the definition of the solution.

The different tasks of the steering activity are therefore interdependent and complementary. Moreover, as the nature and origin of a project influence the steering activity, the project can bring an answer to many unfolding schemes that imply a different steering approach. This is why the design of steering generally depends on the know how and personal experience of an actor.

In order to steer effectively, this actor tackles each event, new solution, and new task through all the implications they can have in all the fields of the project. Therefore, the steering of design appears narrowly linked to the evolution of the design process.

In that way, numerous actors come up with answers in order to effectively steer the design processes in architecture. They propose to "distribute activity in an intelligent manner, to the *right actor,* in order to reach the most systematic possible level of integration of his solution."

2.2 *A predictive and reactive activity*

The design process is often too complex to be entirely conducted in an intuitive manner, without being structured beforehand. A clear framework that imposes to the actor of design a certain "line of conduct" is necessary in order to run the process effectively. However, in order to be effective in the design process, actors need some degree of freedom. They also need to be able to define their own business processes and adapt them to the needs of projects and to the evolution of practices. We consider here the two aspects of a given process. Design is a predictive activity that has to be planned and instrumented. It is an activity for which actions that will be implemented are defined beforehand. At the same time, design is a reactive activity that evolves and adapts as its content changes with the environment and with the personality of the actors that conduct it. All the complexity of the design therefore lies in this duality.

Consequently, we consider that design steering consists of organizing and planning tasks with already identified mechanisms and results. It also consists in managing events, actions and situations that are not initially known and formalized. The success or the failure of a project often depends on how these different unplanned situations are managed and controlled.

3 TOWARDS MODELLING STEERING DESIGN PROCESSES IN ARCHITECTURE

3.1 *Design in architecture: cognitive process and process to be coordinated between actors*

During the last century, numerous approaches were created in order to modelling design process in architecture.

Many researchers such as Pena (Peña 1977) and Alexander (Alexander 1971) consider this process as a sequence of problem solving situations that can be treated in different ways in order to be resolved in a satisfying manner.

These cognitive models have different origins and distinct ways of exploring design processes. They highlight that we cannot currently state that "there exists a consensus concerning this process in terms of definition, structure and roll-out. It seems that there are as much design processes as there are authors." (Bendeddouch 1998).

The roll-out of design has also been described by a sequential model of the design process. According to this approach, the process is made of a sequence of phases. It starts with the description of the problem faced by designers and ends by complete definition of the solution. Moreover, inspired by the organization of Japanese industries and by the models taken from "toyotism", western organizations have adopted

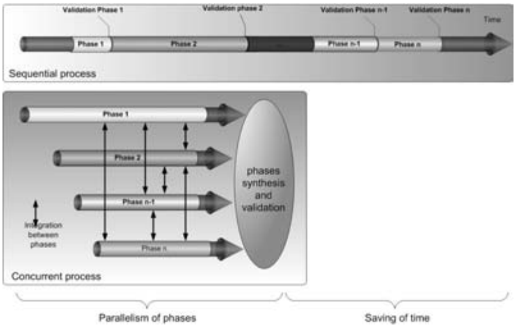

Figure 1. Parallel and integrated process (bottom) and sequential process (top).

a model of concurrent engineering in order to achieve time savings and reduce design costs.

When applied to a building project, concurrent engineering aims at integrating five different but interdependent approaches: landed, usage, the building in itself, execution and financing.

In general way, we notice that the design project in architecture is a space where a set of problems progressively and collectively build up. This means that the construction of the problem is continuous until the building is realized and sometimes even beyond. It is therefore necessary to complete and enrich the "data" from the initial statement with constraints, and negotiated prescriptions. With regard to this, we highlight three interesting facts. First, the problem cannot be isolated from its fluctuating (security standards, zoning regulations. . .) and instable context, which is sensitive to the circumstance. Second, the statement of the problem develops in a social organization framework (organizational complexity of the actors who formulate the problem). Third, some components, constraints or specifications can emerge only throughout this process.

However, the analysis of these models allow us to highlight the fact that design processes are articulated around the three primary activities – problem *analysis*, *proposition* of a solution and *evaluation* of the solution – and that this holds whatever the modeling approach.

Around these activities, which are simultaneously held by every actor during the design, the emergence of the problem and the constitution of the solution are established.

More precisely, the analysis activity is about the exploration of the universe of the project. It is conducted in order to formulate a set of possible problems and then build a point of view beforehand. Therefore it consists of a formulation of the problem to be solved and the constraints related to it. As of the proposition activity, it consists of the construction of a set of solutions in.

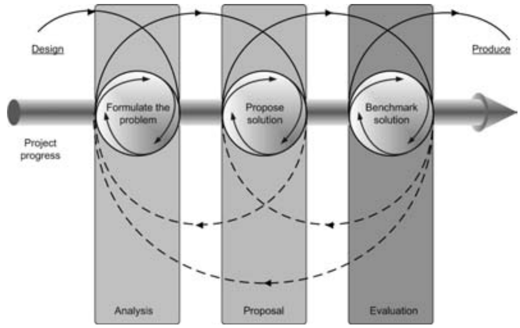

Figure 2. Articulation of the problem-solving in the three proposed primary activities.

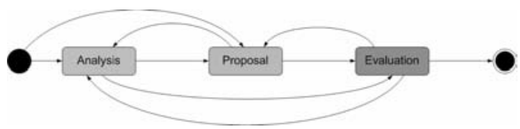

Figure 3. Generic design process in architecture.

Finally, the *evaluation* activity is about the confrontation of the solutions to the individual or collective knowledge.

With regard to this and based on the models previously studies, we propose a combined schema (cf. Figure 2) in order to illustrate the design process, that defines the "problem articulation/solution" couple as the fundamental *module* of a sequential and iterative progression. The combined schema illustrates the correspondence of the design process with the primary activities that we have just revealed. This schema also shows cyclical relationships that can be developed between the different phases of the (design-realisation) process (Conan, 1990). Independently on her entry point in the distributed processes macro-model, an actor has the possibility to undergo the three phases in any order and as long as it is necessary.

Given the diversity of practices, we propose to represent design processes in architecture by a generic process that can adapt to a large number of actors' practices in architecture design (Laaroussi 2007) (cf Figure 3).

Finally, we underline the ubiquist aspect of the generic design process in architecture, based on its primary activities – proposition analysis and evaluation (cf. Figure 4).

3.2 *A steering –driven model of design processes in architecture*

In practice, what allow the pilots to prevent dysfunctions remain their ability to react quickly and their global and transversal vision of design.

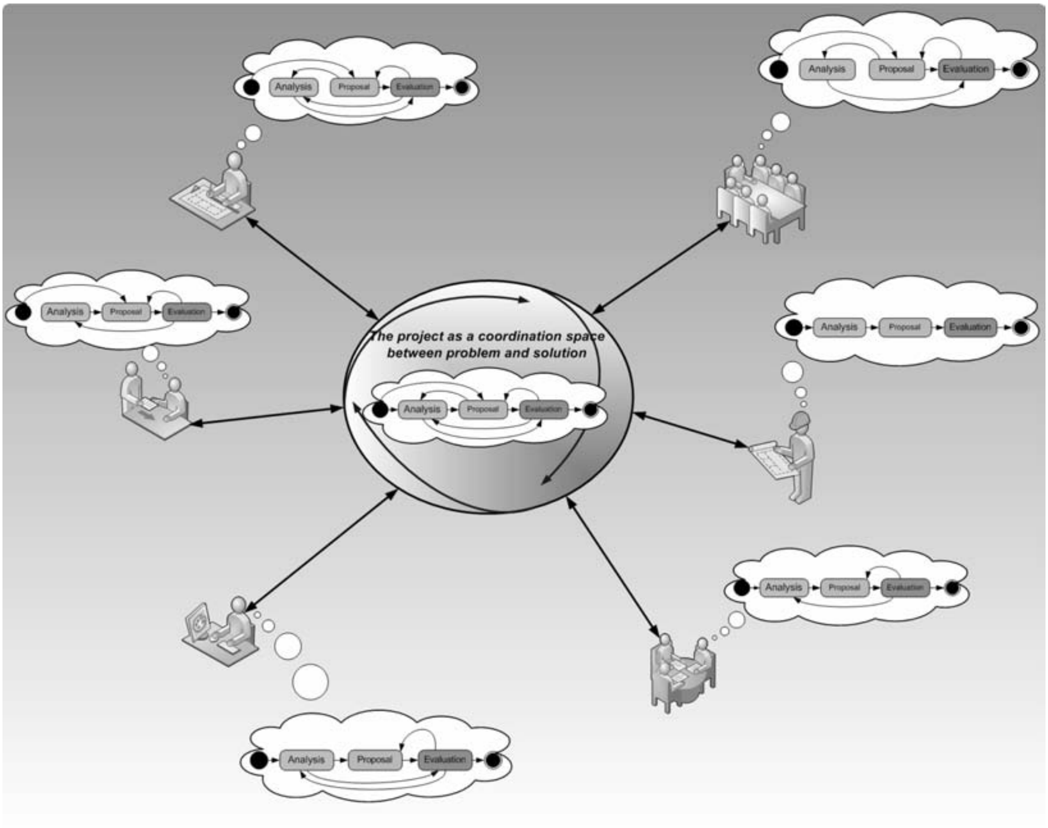

Figure 4. Ubiquitous aspect of the generic design process in architecture.

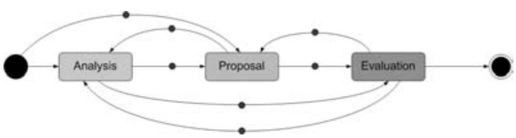

Figure 5. Macro model of design processes steering in architecture.

In order to allow the pilot to monitor the right development of the distributed processes of every actor involved in the design, we introduce the notion of break point. This notion is inspired from the concept of debugger in computer science. Breakpoints are positioned on the macro model (cf. Figure 5). They represent the place and moment where every actor of the process can send an inquiry to the pilot in order to trigger reactions to unexpected situations. These reactions to the unexpected can considerably modify the building to design or hamper the good development of design processes.

These breakpoints represent the reactive part of the steering activity.

In order to formalize the concept of breakpoints, we associate it to two concepts that are narrowly linked, generally implied though omnipresent in design projects. The concern situation and the aimed situation.

The concern situation can be defined as a configuration of a project, at a given time, that does not allow a continuous and effective progression towards the definition of the building to design. It is an obstacle to the progress of the project. It can also be considered as a set of correlated parameters and facts that lead actors of design to situations they did not imagine or anticipate. Regular, pre-established processes are usually unadapted to these situations. In practice, encountered situations are considered as problematic/concern situations only when they involve several fields of the project. In the opposite case, these situations will be treated locally and will not trigger any specific treatment. In order to be identified as a concern situation and be treated consequently, a given situation has to be declared at the pilot's level who measures its importance and decides to launch or not the problem-solving process. By analyzing some

Figure 6. Pilot module aimed to analyse concern situations.

design projects, we have identified situations that led to the triggering of concern situations: e.g. the lack of information, the unfeasibility of the study, the non-respect of regulatory constraints, the non-respect of specifications, incoherencies between the propositions submitted by different actors, and incoherencies between the artifacts produced by different actors, etc.

The aimed situation is a configuration of the project that eliminates the concern situation. It also consists of heading towards the definition or the reformulation of the problem. In this manner, the design actors explicitly define which aspects of the project or building will be concerned by the modification of the project configuration. It allows them to identify in which fields they should operate, in order to reach the new configuration of the project. This work is comprised in a project steering activity and therefore directly concerns the steering team. One particularity of the aimed situation is that it includes a definition of the objective to reach as well as the description of the method used to achieve it. In fact, the aimed situation is built and stated in a way that allows it to be. It describes not only the configuration that the project intends to reach, but also the means to achieve it. It can be described, on one hand, as the identified problem to be solved and, on the other hand, as the expression of a solution for the encountered concern situation.

4 INSTRUMENTATION OF STEERING DESIGN PROCESSES IN ARCHITECTURE

The principles selected to assist the steering of design processes are under implementation in a software application that bears the concepts of the proposed model.

Principle 1: effective steering requires to define the relevant problem (to solve) and state it in an adequate manner. In order to achieve this, a file that structures the definition of a concern situation helps formalizing the consequences of the problem that threatens the design in progress. It also allows estimating the risks and their possible consequences facing the project. The pilot, therefore, has a relevant basis of analysis in order to decide which problems are relevant for solving and how they will be solved (by phone, in meeting session, according to a given procedure, etc.) (cf. Figure 6). A file describing the aimed situation then allows to clearly state the problem by requiring a definition of the objectives and the implementation framework necessary to achieve them (cf. Figure 7).

Principle 2: the evaluation of solutions relies on an evaluation file that allows negotiation between the pilot and the concerned actor.

This makes it possible to suggest modifications and validate them (cf. Figure 8).

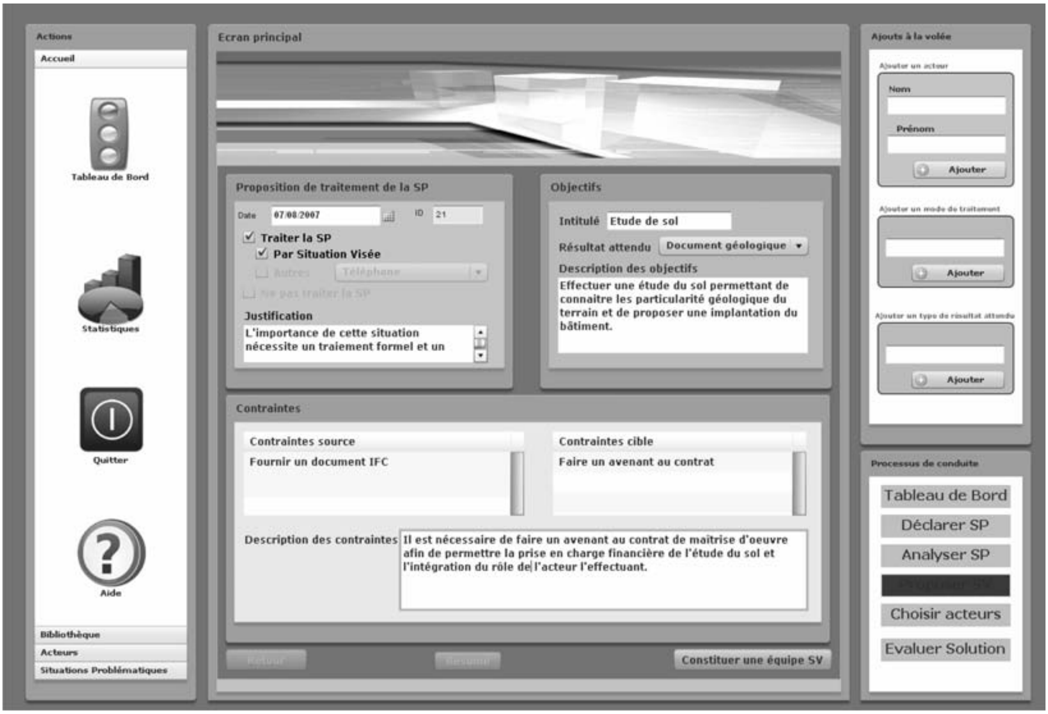

Figure 7. Pilot module helping to propose the aimed situation.

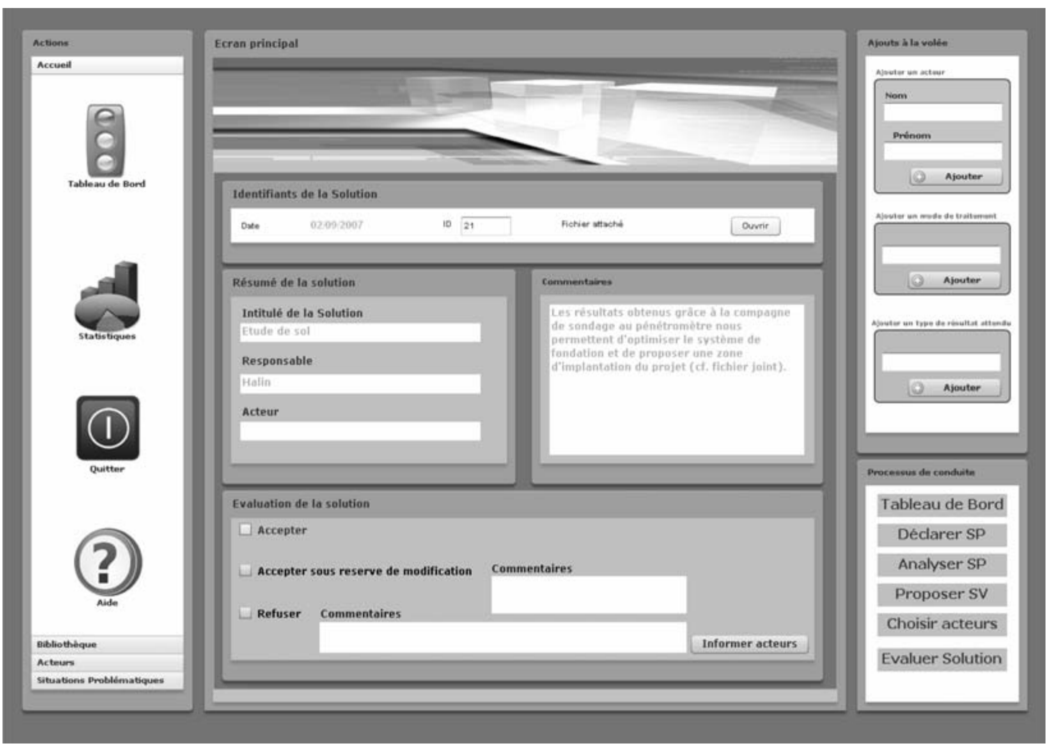

Figure 8. Pilot module aimed to evaluate the solutions.

Figure 9. Project dashboard.

Principle 3: in order to be informed of the progress of the design project, one has to know the status of the distributed processes. A dashboard allows the pilot to monitor the evolution of the work and to be informed about the concern situations (cf. Figure 9). The pilot monitors, which situations have been solved, are in process of being solved, or have been dropped, as well as verify the progress status of the solving of aimed situations.

5 CONCLUSION

Through our approach, we have presented a model for steering distributed design processes in architecture. The applicative objective of our research is to allow the pilot of the design processes to have a global view and the dynamics of the entire distributed design process (concept of dashboard). The pilot therefore has a tool that allows him to visualise the state of the processes and sub-processes in any moment of the design process. Thanks to the proposed software application, the pilot will be able to make the adequate decisions in order to reach the desired performance. Moreover, this research will contribute to knowledge capitalization through the project information system. This can be achieved by compiling into experience libraries all the dynamics produced during the design processes in order to use them for future problem solving in similar situations.

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Semantic support for construction process management in virtual organisation environments

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ABSTRACT: We describe a new conceptual approach for ICT supported construction process management in virtual organisations based on the use of a set of infrastructure and domain ontologies defined in OWL that can be consistently referenced by both general-purpose and domain-specific ontology-enabled services and tools. We present also a novel Business Process Object concept and show how it can help to decompose formally defined high-level business processes to executable "atomic" processes and translate these into executable Web Services described in BPEL. The provided small practical example enables easier understanding of the developed concepts, and the reported realisation details from the EU project InteliGrid and the German project BauVOGrid shed light on already achieved practical results as well as planned further research and development activities.

1 INTRODUCTION

Process centred work is a challenging issue for the construction industry. Companies and especially Virtual Organisations (VO) are largely unaware of the underlying project workflows, and very few processes are explicitly captured and formally defined in current practice. Hence, knowledge is only bound as tacit knowledge by the companies' personnel. When knowledge carriers retire or the company is restructured without efficient procedures for replacement of experts, the knowledge is lost.

This challenge can be met by organising the work along an explicitly defined, IT-supported integrated process management. In other industries like mechanical engineering and e-business this is in fact already being done. The approach has the potential of improving competitiveness by advanced capabilities for planning, simulation, monitoring and scheduling during the construction process. However, defining processes in a semiformal specification using available tools like the ARIS Toolset (Scheer & Jost 2002) is only the first stage of implementation. Up to now, the resulting models are used as input for software developers which code the final application logic. Unfortunately, while this approach is appropriate for various, predominantly static businesses, it is less adequate for the highly dynamic construction VOs, where processes are frequently changed. Moreover, the currently applied long modelling procedure leads to inevitable loss of flexibility, as even small changes in processes cannot be easily reflected in the process model. The implemented application logic has to be changed too, every time.

To overcome this dilemma, there is a strong need for an integrated process-centred approach, where the underlying process model itself is implemented without major delays, and changes in the model are reflected and propagated downstream directly. Development of such an approach comprises two explicit research efforts: (a) methods for the automatic translation of sufficiently defined conceptual process models to computer-interpreted business processes, and (b) a bottom-up integration framework that provides for coherent and flexible integration of resources involved in and affected by these processes at runtime. There are research efforts targeting challenge (a) by implementing automated translators that, for example, generate BPEL (Business Process Execution Language) files out of conceptual process models like BPMN (Business Process Modelling Notation). These generated BPEL files can be interpreted at runtime, thereafter. However, within generic process definitions there are a lot of references to resources like users involved or performing the process, files or database records that are used, types of service resources needed to perform a specific operation and so on. Such resources can act as process input or output, or are affected during the process execution. As long as there is no explicit referential grounding for each resource involved, a more advanced process can not be instantiated easily, out of a generic process definition. This requirement entails the need for a model that can be used coherently to describe and reference a wide range of heterogeneous resources that can be involved in business processes. An ontology-based approach for such a framework, targeting the objective of coherent integration of a broad range of resources, potentially involved in business processes, is described in this paper.

2 BACKGROUND

2.1 *Process modelling and execution*

The concept *process* has several denotations. The verb means to handle, as in processing an error, or processing a message. The noun sometimes refers to a program running in an operating system, and sometimes to a procedure, or a set of procedures, for accomplishing a goal. In each case, the connotations of the term are movement, work, and time; a process performs actions over some interval of time in order to achieve, or to progress to, some objective. The concept of a *business process* can be understood as the step-by-step rules specific to the resolution of some business problem. *Business process modelling* (BPM), sometime called business process management, refers to the design and execution of business processes. (Havey 2005).

Whereas most of the applications used in the construction industry are used as tools by engineers, which keep track of the underlying business processes and information flows by their own, IT-supported business process management sustainably influenced other industries like e.g. mechanical engineering and e-commerce. Approaches, methodologies and standards developed there can be applied for construction industry challenges, even if construction processes introduce the essential demand for more flexibility and adaptivity than needed for business processes of more structures industries.

Standardised business process specifications have been developed by different organisations. The Business Process Modelling Initiative (BPMI) and the OASIS Group developed very promising specifications with the Business Process Modelling Notation BPMN (OMG 2006) and the Business Process Execution Language BPEL (OASIS 2007). BPMN provides a graphical notation language to model processes in a user friendly way. BPEL, also known as BPEL4WS (BPEL for Web Services) defines processes in terms of services using the XML language and targets their straightforward execution by dedicated interpreters. A mapping specification exists as part of the BPMN specification which can be used for the translation of processes modelled with BPMN to executable BPEL process definitions. Since 2007 the BPEL extension called BPEL4People exists. It targets human interactions with BPEL processes, which may range from simple approvals to complex scenarios such as separation of duties, and interactions involving ad-hoc data (Agrawal et al. 2007). Unfortunately, software support for this extension is still weak.

Further specifications for Business Process Modelling include the Web Service Choreography Description Language WS-CDL (Kavantzas et al. 2005) of the World Wide Web Consortium, the XML Process Definition Language XPDL (WfMC 2005) of the Workflow Management Coalition (WfMC), the Business Process Definition Metamodel BPDM (OMG 2003) etc.

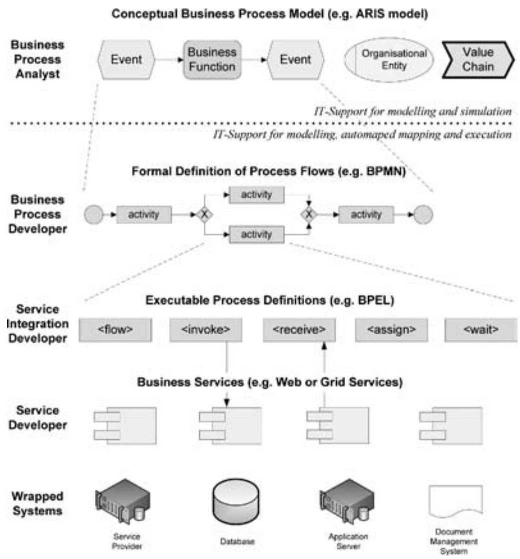

Figure 1. Layers of Business Process modelling, integration and execution.

For conceptual modelling of business processes the ARIS methodology (Scheer 2000) is of importance. It comprises an integrated set of inter-related models (value chain, organisational, functional, data model), built around a semi-formal modelling approach with extended event-driven process chains (eEPC) that play integrating and control role in the ARIS framework. The focus of the methodology is on capturing, externalisation and improvement of business processes. The outcome of the modelling process is a comprehensive conceptual model that, however, cannot be directly translated to executable process definitions. Hence, there is a conceptual gap between the top-down conceptual processes and the bottom-up BPEL and BPMN definitions, i.e. between the two topmost layers in Figure 1 above.

Whilst integrated IT support from the lowest layer of business systems up to the layer of the formal process definitions developed by Business Process Developers is available, no formal methodology supports a automated transition from the high-level semiformal conceptual process models to the formal executable models that process developers can implement.

2.2 *Ontologies*

The use of ontologies has a long tradition in knowledge management. In its extended definition, based on the original definition by Gruber (1993), the term ontology stands for a “formal explicit specification of a shared conceptualization”, where formal means that it is expressed in a computer readable und interpretable representation, explicit means that it contains clear, unambiguous, assertive definitions of concept types and constraints modelling the targeted domain of discourse, and shared means that it is used to define a common standard in the targeted domain. The term conceptualisation refers to the objects, concepts and other entities that are presumed to exist in the domain of interest and the relationships that hold them (Genesereth & Nilsson 1987) conceptualisation is an abstract and simplified model of the real world, represented for the purpose of knowledge management and exchange.

Ontologies can be applied to meet different important business requirements (Uschold et al. 1998). First, information integration targets the objective of relating heterogeneous information resources distributed across different information systems. Second, communication between employees and IT systems can be improved by shared ontologies. Third, the flexibility of data models and business processes can be enhanced if they are grounded on more expressive and easier to extend ontologies. Last, but not least, ontologies can be applied within end user interfaces, in order to realise more efficient manmachine interaction.

Different types of ontologies exist to meet such different requirements: (a) *Core Ontologies* model generic basic concepts targeting a broad range of domains. (b) *Representational Ontologies* establish a modelling methodology, i.e. they do not define “what” to model, but “how”. (c) *Domain Ontologies* capture the knowledge of a specific domain. Within that domain they have to be generic and reusable, i.e. not focused on one specific application. (d) *Method and Task Ontologies* are dedicated to the modelling of problem solving methods and processes, and the semantic meaning of concepts used within the definitions. (e) *Application Ontologies*, which, as a subtype of Domain Ontologies, model mainly concepts that are dedicated to the use in an explicit application. Calero et al. (2006) provide a comprehensive overview of further classification approaches.

Whilst up to a couple of years ago projects developed ontological representations more or less from scratch, the majority of present approaches has moved to available ontology standards, such as the Resource Description Framework Schema (Brickley & Guha 2004), and OWL (Dean & Schreiber 2004) as a more appropriate specialisation of RDF Schema. Examples of OWL-based ontologies are the Standard Ontology for Ubiquitous and Pervasive Applications SOUPA (Chen et al. 2005) and the Ontology Framework for Semantic Grids (Gehre et al. 2007) developed in the InteliGrid Project.

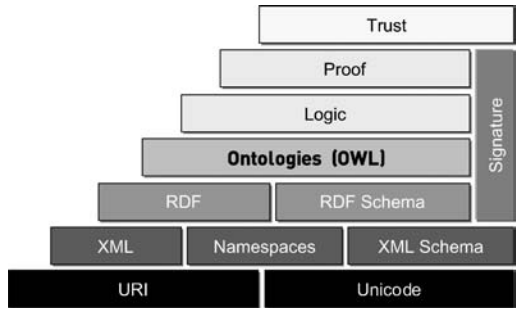

Figure 2. Semantic Web Stack (Berners-Lee et al. 2001).

2.3 *Semantic web*

The semantic web identifies a set of technologies, tools, and standards which form the basic building blocks of an infrastructure to support the vision of the Web associated with meaning (Cardoso 2007). The OWL based ontologies, discussed in the previous chapter, are part of this infrastructure, which combines different standards not only from a conceptual point of view, but also enables syntactical and structural compatibility between most of the different layers, shown in Figure 2 above.

Within this Semantic Web Stack, often also called “layer cake”, the lowest layer is established by Unified Resource Identifiers (URIs) which are formatted strings identifying physical or abstract resources, and the Unicode as the unifying encoding schema.

Syntactical interoperability is ensured by the XML, XML Schema and Namespaces layer which enables flexible and standard conformant structured documents with user defined vocabularies, clearly separated by unique namespaces.

The basic data model of the Resource Description Framework RDF relies on the XML syntax and is used for modelling simple statements about resources (objects in the web). RDF Schema provides a type system for RDF with modelling concepts (classes, properties and values) for building object models.

Built on top of RDF and RDF Schema, ontologies of the semantic web with their more advanced expressivity are used to model detailed descriptions of resources, their semantic meaning and the relationships between them. Within this layer the ontologies of the Semantic Web Stack are constrained to Description Logic constructs. The dominating ontology language for the Semantic Web is OWL (Dean & Schreiber 2004).

The layer of Logic is dedicated to the modelling of application specific declarative knowledge using more complex first and second order logic constructs, as an extension to the simpler description logic based ontologies. Because its complexity and no guarantees for computation and reasoning processes, until now the Logic layer has not achieved an adequate level of relevance in practice.

Facts derived using automatic reasoning processes should be made more traceable within the Proof layer.

In parallel to the layers from RDF to Proof the concept Signature provides the capability to assign signatures to the statement of a model, i.e. to provide additional provenance information.

On top of the Semantic Web Stack the concept of Trust can be found. It is dedicated to the authentication of identities and verification of trustworthiness of data and services.

Semantic Web Technology is already used for different advanced application domains, as e.g. Semantic Web Services (Cabral et al. 2004), the Semantic Grid (De Roure 2003), and Semantic Search Engines like Swoogle (Ding et al. 2004).

Of utmost importance for the work described in this paper are the capabilities of the Semantic Web Technology to uniquely address heterogeneous distributed resources and to describe them with a flexible, expressive and standard-conformant ontology language as OWL is. The good tool support for Semantic Web standards is another vital advantage to mention.

3 SPECIFIC CONSTRUCTION RELATED REQUIREMENTS

Explicit process centred work is not achieved until now in the construction industry. In large companies processes are well documented and standardised, but this does not mean that there is dedicated IT-support for integrated process management as in various other industries.

In order to apply the technology of integrated process management to the construction industry, a set of sector-specific requirements has to be considered:

– Flexibility in process modelling is essential for construction VOs, as each project unites a unique set of companies in order to create a unique product;
– Construction VOs are temporary relationships between companies which can be competitors in other projects at the same time. Hence, the privacy of internal information and processes is essential;
– In contrast to e.g. the automotive industry, roles in construction projects can vary. A company which is the general contractor in one project may be a subcontractor in another one. Therefore, even the implementation of standard processes imposes basic remodelling for new VO projects;
– Frequent remodelling of processes reveals a demand for generic building blocks and process templates that can be applied in order to avoid starting from scratch each time.

Subsuming these requirements, flexible process models and an integrated holistic IT-support for process modelling and implementation are essential in order to satisfy the higher cost-benefit ratio that follows from the reduced lifetime of implemented construction processes, compared to other industries.

However, it is important to understand, that not all activities described by semiformal conceptual process models can be translated to process definitions that are executable by IT systems. Complex human activities, loosely structured support processes and largely paper-based activities can be only partially in the range of process-centred IT-support.

4 CONCEPTUAL APPROACH

The above requirements can be met by closing the currently existing gap between user-friendly tools for semiformal conceptual process modelling, like e.g. the ARIS toolset, and technically oriented process and workflow execution frameworks that work with executable process definitions, like e.g. BPEL. Using BPMN for which an automated translation to BPEL exists does not help much here because it is heavily oriented to IT-workflows and lacks the needed flexibility to be accepted by business process analysts and engineers in the construction sector.

We argue that this gap can be closed by providing a set of semantic web ontologies which model generalised process concepts and process patterns called *Business Process Objects* (BPO).

The idea of a Business Process Object stems from the popular conception of a Business Object which is seen as “a physical or logical object of significance to a business” (UIS 2006), whose aim is to “do something practical and useful of itself rather than contributing towards the achievement” (Wikipedia 2006). We understand a Business Process Object as an extension of current Business Object specifications in that it enables better and more consistent binding of a real-world concept, representing a product or service which is the goal of a business activity, with the actual business process for its realization. A Business Object is typically comprised of a (sub) schema, population of the schema, methods assigned to the object providing various means to access and process the data, and (optionally) business rules providing quality management checks. A Business Process Object extends that definition by focusing on the process in which the business object is processed, the actor performing that process, the related actors to be notified and receive results from the process, and the services and tools needed to perform the process. Its formal definition is provided by a *Process Ontology* based on the eEPC model providing a common formalism for all involved components (Katranuschkov et al. 2007).

The use of BPOs can improve modelling speed, consistency and quality of conceptual process models. Standardised BPOs can be used/referenced within conceptual process models and on the other hand it is possible to translate and implement them on the process execution layer, i.e. the ontologies act as a rich model shared by the conceptual process modelling and process execution domain.

As shown in Figure 3 below, semiformal conceptual process models have to use/reference concepts (class definitions) of agreed ontologies within its model, instead of non-standardised arbitrary names like “order”, “purchase order” or “bid”. As part of an ontology such concepts have a full semantic context including a range of attributes, an inheritance hierarchy, references to related concepts, constraints for their usage and rules to ensure model consistency. Ontology concepts are domain oriented, i.e. they represent concepts of the end user domain and speak the end user’s “language”. Using them in process definitions does not pose a high challenge to the users.

Enriched with such ontology-based information the semiformal conceptual models are much better prepared for automated translation to executable process models as model entities described by ontology-based specifications with their formal semantics can be mapped in a formal way to IT entities described in e.g. WSDL and BPEL definitions.

However, to achieve the full potential of the approach, ontologies are not only used for referencing concepts within the conceptual process models.

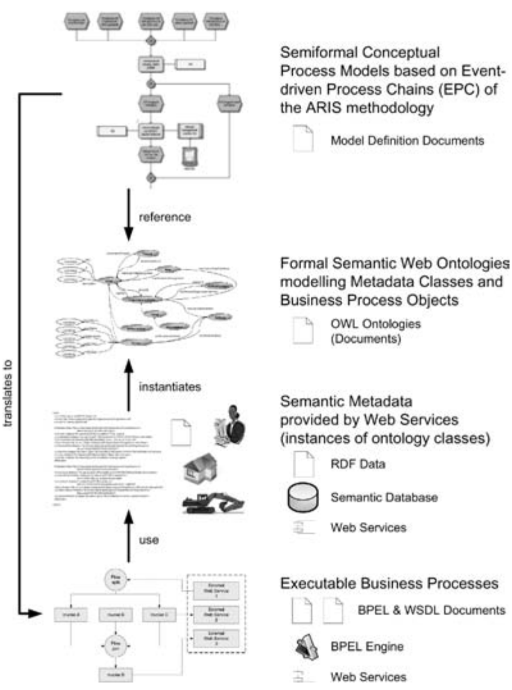

Figure 3. Use of semantic web ontologies to close the gap between conceptual and executable process models.

An integrated ontology framework can apply these ontologies for capturing and management of semantic metadata about real and IT-objects. These objects (actors, companies, information resources, services, machines, etc.) can be represented as instances of ontology classes within a dedicated ontology service. The objects themselves (files, orders, users, etc.) can be managed somewhere else, the ontology framework just has to store rich metadata about them. Within the integrated ontology framework, harmonised object descriptions include references to their real objects, i.e. they act as their proxies. Thus, it becomes possible to model detailed relationships and coherencies between diverse entities, even if they are hosted by distributed heterogeneous IT-systems. The ontology-based object representations managed by Semantic Metadata Ontology Services can be referenced and used by the executable business processes.

In order to demonstrate the approach a simplified example is provided in the remainder of this section. In that example a high-level BPO called “Prepare Structural Design”, shown in Figure 4 below, is defined, decomposed to atomic BPOs and translated to an executable BPEL format.

The example represents the activities that have to be performed in preparation of a model-based structural design. It starts with the extraction of a partial model out of a complete IFC-based product model that is subsequently stored at the machine of the end user, in this case represented by the structural engineer.

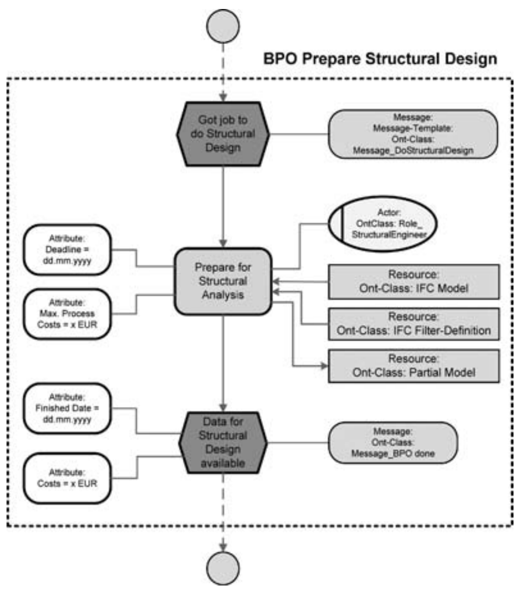

Figure 4. Main properties of the high-level Business Process Object “Prepare Structural Design” (reduced and simplified view).

This high level BPO is not directly translatable, but consists of three atomic BPOs that have a more detailed process structure which can be translated to an executable grounding. A simplified decomposition view to the three atomic BPOs is provided in Figure 5.

The two most important differences between high-level (abstract) BPOs and atomic BPOs are:

- Whereas high-level BPOs usually define process properties by generic ontology classes (types) of involved resources, atomic BPOs can manage references to runtime ontology instances.
- In contrast to high-level BPOs, atomic BPOs provide an OWL-S Process Description (Alesso & Smith 2005) that specifies the executable grounding of the process in a more generic way than in BPEL. Moreover, an OWL-S process description may provide a further decomposition to several atomic processes that can include standard WSDL bindings.

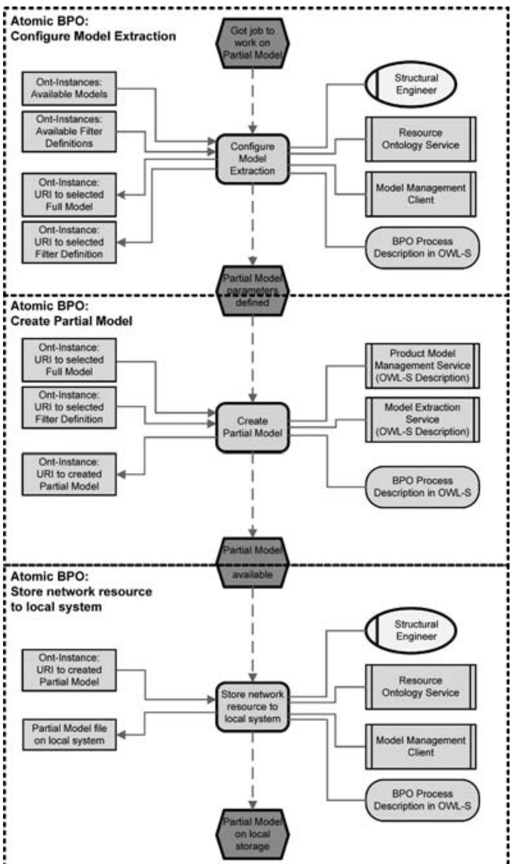

Figure 5. Decomposition of BPO “Prepare Structural Design” to three atomic BPO (reduced and simplified view).

Indeed, whilst a virtual machine for OWL-S does already exist, it is not yet mature for application in complex business scenarios and can only be used for proof of concept purposes. Therefore, it is a more promising approach to translate the process descriptions to executable process definitions in the favoured BPEL standard.

The BPEL representation of the BPO is shown in Figure 6 below in a reduced and simplified graphical representation, as the full XML specification according to the BPEL standard is not feasible for the space available in the paper. The BPEL4People extension is not considered within the example. However, construction processes can heavily profit of this BPEL extension that is able to model human interactions.

The final BPEL definitions and corresponding WSDL service specifications can be used then as input for available BPEL engines. These engines already provide a good performance and are ready for use in complex business scenarios.

Ontology classes and instances are not directly visible here anymore, as BPEL only supports XML Schema standard data types. However, URIs are used for referencing ontology instances (object metadata) within the Ontology Services. The dedicated client applications and services that are applied in the process are able to track from URIs to ontology-based metadata and finally to the “real” objects.

The downstream propagation of ontology-based information from the semi-formal conceptual process

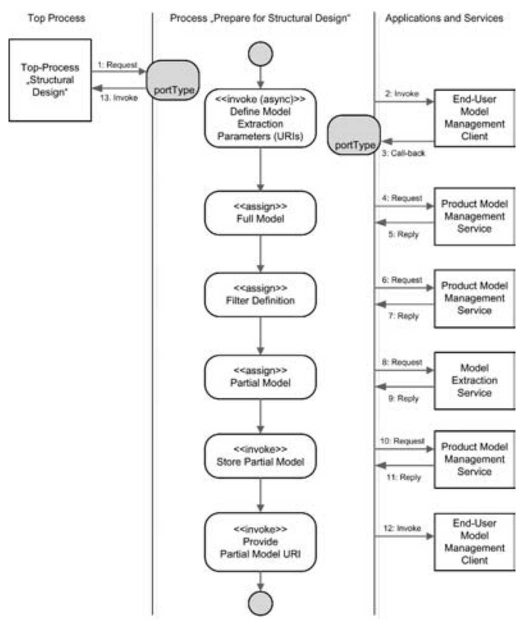

Figure 6. BPEL process for BPO “Prepare for Structural Analysis” (reduced and simplified view).

models that reference ontology classes to executable runtime models that integrate metadata as ontology instance data is illustrated in Figure 7 below.

The figure shows the BPO slot "IFC Filter Definition" and its decomposition to atomic BPOs at runtime. The high-level BPO just references the ontology class "IFC-Filter-Definition" whose model is shown partially below the BPO. The atomic BPOs – which are more related to runtime aspects of the process – model slots that can capture lists of URIs or single URIs, respectively. Within the BPEL process this translates to *Strings* representing references to the Ontology Services for Semantic Metadata that act as central infrastructure services providing complex ontology-based metadata for registered objects. In the example, the URI is resolved to instances of class "IFC-Filter-Definition" with expressive semantic information about these objects, including related access profiles that are used to describe from where and how to retrieve the related real objects, in this case – how to get the file-based filter definitions.

5 REALISATION

For the realisation of the developed approach four principal tasks need to be accomplished: (1) Infrastructure and domain ontologies have to be modelled, (2) Ontology Services providing the semantic metadata have to be developed, (3) Procedures and mapping rules for automated translation of atomic BPOs to executable process definitions have to be defined, and (4) Rules for usage of ontology-based models in

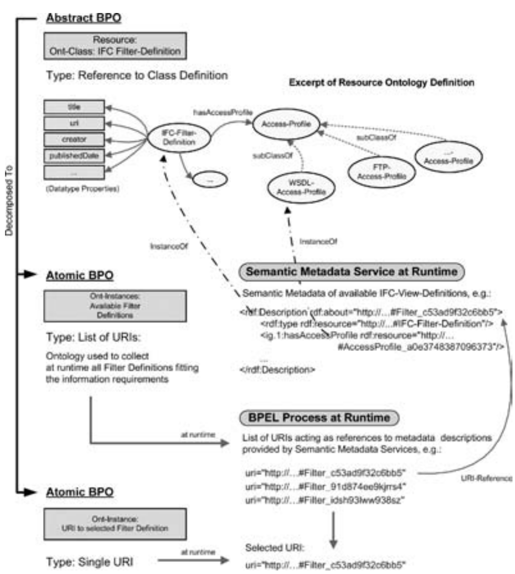

Figure 7. Ontology-based information integration trough process decomposition and at BPEL-based process runtime.

semi-formal conceptual process models have to be defined. Currently, the work on the first two tasks is largely finished.

Performing Task (1) several ontologies were defined (Gehre et al. 2006):

- A *Resource Ontology* dedicated to the representation of all data resources in the environment (files, documents, databases, product models, product model filters, etc). Its possible domain extensions may incorporate ontological representations of discipline-specific product data models, as e.g. various IFC extensions.
- A *Service Ontology* formally defining the relevant services to a process using the definitions of the Resource Ontology to specify the content exchanged/provided by these services. Domain extension of this ontology is optional but may provide service subclasses that are more tightly bound to respective business requirements. Currently, as Service Ontology OWL-S is used.
- An *Organisational Ontology* defining the concepts of actors, project structure, persons, organisations, roles, and respective access control and authorisation constraints.
- A *Business Process Ontology* providing an encompassing view on business processes and the related business requirements. It relies heavily on the definition of the preceding three ontologies.

Additionally, a *Defect Ontology* is currently under development for application of the approach in a real business case that targets advanced mobile defect management in construction projects, applied in a grid-based environment.

The ontology services for the management of semantic metadata, i. e. task (2), have been developed within the frames of the EU project InteliGrid (Dolenc et al. 2007) and are currently being enhanced in the frames of the German BauVOGrid project (Katranuschkov 2008). All ontology services are developed as Web Services, so that easy access and standard conformity is achieved. In its current version the ontology framework manages ontology-based metadata about organisational VO aspects, information resources, services and Business Process Objects. For more information about the ontology services, their integration within a complex grid environment and the developed set of dedicated client applications see (Gehre & Katranuschkov 2007) and (Gehre et al. 2007).

Still under development are the abovementioned tasks (3) and (4). This work is carried out as part of the BauVOGrid project in which more generic and domain specific atomic BPOs are modelled and the mapping to BPEL process definitions is being examined and specified. In parallel, work on defining rules and modalities for using ontology-based models in semi-formal conceptual process models is performed in collaboration with experts from the conceptual process modelling domain, BPEL experts and end users.

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Building information modelling and ontologies

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Semantic product modelling with SWOP's PMO

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ABSTRACT: The European Semantic Web-based Open engineering Platform, project (SWOP 2008) is concerned with business innovation when specifying products to suit end-user's requirements and objectives. This paper will show how Semantic Web (SW) technology of the Word Wide Web Consortium (W3C) can be used to its fullest to model the products to be developed and configured. It introduces a Product Modelling Ontology (PMO) as the main result of SWOP. It is in essence a fully generic, freely reusable 'upper ontology' specified in the Web Ontology Language (OWL), the most prominent SW technology (OWL 2008). PMO contains in a necessary and sufficient way all constructs to define any end-user product ontology, modelling all relevant end-user's product classes, properties and interrelationships (in particular specialization and decomposition) together with cardinalities, data types, units and default values. Rules in the form of assertions that have to be satisfied and derivations that can be executed add the more complex product knowledge aspects. PMO has already been applied in many end-user situations and other R&D projects.

1 THE SWOP PROJECT

1.1 *Objectives*

The European SWOP, Semantic Web-based Open engineering Platform, project is concerned with business innovation when specifying products to suit end-user requirements. There are two main business drivers behind this innovation: (1) to reduce wasted effort in terms of cost and time in re-designing and re-specifying products when for the most part the work has been done before, and (2) to configure solutions from pre-defined partial solutions ('modules') rather than design from scratch. When there are choices, product configurations are optimized in SWOP by applying Genetic Algorithms (GA) so that the resulting product is not just a valid solution but even a near-optimal solution that can be achieved following design constraints, end-user requirements and optimisation criteria.

SWOP shows how semantic web technology can be used to its fullest to model the products to be developed and configured. It introduces a generic, reusable ontology for product modelling enabling product decomposition, the specification of units for properties, the handling of default values and the various types of ranges over property values needed to fully describe both the solution and the requirements side with respect to those products. A special topic addressed is the bridge between semantic and non-semantic information in the form of documents, drawings or even visualisations linked to or better, derived from, the semantic information. As an example we will show how IAI IFC data (an open standard for product representations in the construction industry sector) can be fully derived from the intelligent object data involving both semantic and technical mappings (from Semantic Web to ISO STEP technologies).

What unifies this apparent diversity mentioned in the introduction for 'product' is the approach SWOP is taking. First, whatever the sector and particular application are, every aspect is reduced to semantic description – the product itself, the user need, the external influences, the evaluation (i.e. optimisation) criteria, the product's components that make up the product etc. Semantics are the meaning about something, shareable by people and computer systems.

So, depending on context, it may be the modelling of a 'client requirement' view of a product, a ‘front-office’ sales department’s ‘black box’ view, a ‘back-office’ supplier’s ‘white box’ view including all design details, or a process-oriented view on how to fabricate a product. Semantic descriptions (in the form of ‘ontologies’) are only possible with knowledge of the domain – what the concepts are that give the meaning. This is important not only to the modelling, but also to the user interface in configuration tools. Configuration tools are used to configure solutions. The engine of a configurator may be fairly generic, but the way it is veiled for the user is very context specific. In SWOP, configurators appear in two guises – as tools to formalize all product knowledge and as tools that configure those reference designs according to individual requirements leading to an end product for use.

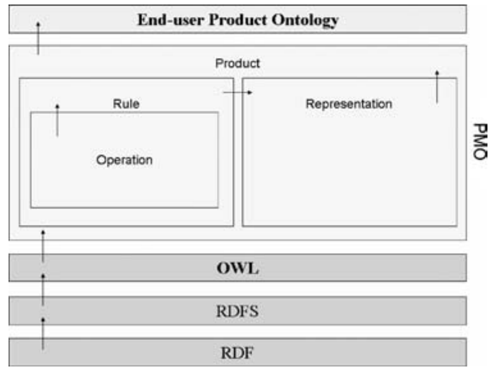

Figure 1. Layered product modelling.

2 STATE OF THE ART

2.1 *ISO STEP*

The oldest initiative to standardize product descriptions is ISO STEP covering both (1) technologies like STEP Physical File Format (SPFF) for the syntax of the data and the EXPRESS language as syntax for the data structure and (2) the data structures themselves. SPFF can be abstracted via a late-binding Application Programming Interface called Standard Data Access Interface (SDAI).

The problem with STEP is that the technologies involved are overtaken by web-based variants and that the models have been proven to be to complex and difficult to implement.

2.2 *IAI IFC*

Especially in the building industry, the actual modelling work in STEP was slow and not resulting in the right data structures. The initiative was taken by software vendor’s to start the International Alliance for Interoperability (IAI) to develop a model in STEP technology called the Industry Foundation Classes (IFC) containing roughly three main parts:

– a limited semantic part,
– a large less end-user oriented geometry part, and
– a small escape meta-model part (for proxies and property sets).

However, despite its limitations it is the best specification currently available for the building industry sector for Building Information Modelling (BIM 2008).

2.3 *W3C Semantic Web (SW)*

Although the web gave us already an alternative for SPFF namely eXtensible Markup Language (XML) and an alternative for EXPRESS namely eXtensible Schema Definition language (XSD); the power of the languages is limited to structure only and not really proving mechanisms to add ‘real’ semantics in the form of concepts, properties and rules. This is exactly what the Semantic Web Activity in W3C DOES bring us in the form of Ontology Web Language (OWL) and RDFS-XML as syntax for the content according to OWL-expressed ontologies.

In the next chapter we will tell how we extended this generic approach for the use in (semantic) Product Modelling.

3 SEMANTIC WEB TECHNOLOGY

3.1 *Introduction*

PMO, short for Product Modelling Ontology, is the main result of SWOP. It is in essence a fully generic, freely reusable ’upper ontology’ (generic data structure with knowledge) specified in OWL, the most prominent Semantic Web (SW) technology from the World Wide Web Consortium (W3C). OWL is a more modern, fully web-based and distributed variant of the traditional ISO STEP technologies like EXPRESS and SPFF. Technically, PMO can be seen as a protocol stack layer on top of the series Internet, WWW, XML, RDF, RDFS and OWL specifically targeted at a generic way of ‘product modelling’. End-user Products (on any complexity level so including standard catalogue items) will also be modelled by OWL ontologies reusing PMO.

PMO contains in a necessary and sufficient way all constructs to define any end-user product ontology, modelling all relevant end-user’s product classes, properties and interrelationships (in particular specialisation and decomposition) together with cardinalities, data types, units and default values. Rules in the form of assertions that have to be satisfied and derivations that can be executed add the more complex product knowledge. From this semantic end-user ontology in principle any representation/visualisation can be derived (think IAI IFC, COLLADA, OpenDXF or GDL). Currently, IFC2x3 STEP (SPFF) files and their XML variants (according to ifcXML) exports are supported. The primary semantic ontologies from which these formats are derived are however always the specifications that are used to integrate existing third-party software applications. Another, maybe even more interesting, application is where they form the basis for new advanced semantic applications such as smart product configurators often involving optimisation techniques such as Genetic Algorithms (GAs).

In contrast to approaches trying to develop THE ontology for a given domain, PMO envisions a more flexible, evolutionary and moreover distributed approach (in specification, use and maintenance) to product modelling for both software integration and development. PMO can be used in general by Semantic Web-tools such as the open source Protégé or the commercial TopBraid Composer (TBC) toolkits. More specialised support is availed by the SWOP modelling tools developed by TNO in SWOP (PMO Editor and PMO Configurator) that are currently being integrated. Some examples of the use of the PMO tools in the Building Construction context have been developed and will be presented along the paper.

3.2 *The Resource Description Framework (RDF)*

The basic specification underlying the semantic web technologies is the Resource Description Framework (RDF). This is a very well defined basic building block. Many researchers have made it a logically and mathematically sound approach. In its essence RDF is a semantic network graphically equivalent to a so-called 'directed graph'. This graph is fairly simple: there are nodes and directed edges between these nodes. Two nodes and one edge from one node to the other makes a 'triple' and a directed graph is nothing more than a set of these triples (triples become connected via shared nodes).

The input node is called the 'Subject', the output node the 'Object' and the edge the 'Predicate'. This basic construct is used to model almost everything for both information content/data and structure! Changing data or structure (or the links between tem) finally comes down to creating or deleting triples as an atomic action. Said otherwise, the sets of triples can be regarded as the optimally normalized relational model.

The essential message here is that with RDF we can describe any web content/structure/meta-structure/etc. (when using 'type' in nested ways) in the most simple way. With an RDFS/OWL-hat on we distinguish the structure from the data.

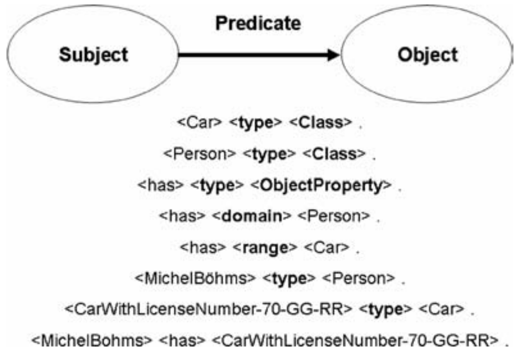

Figure 2. RDF example.

The triples can be represented in several, equivalent, ways. The above example used N-TRIPLE. Other forms are N3 (non XML-based), or RDF/XML or RDF/XML Abbrev(iated). The latter is a more compact form sacrificing however determinism. In RDF/XML Abbrev. there exist more than one equivalent RDF-XML files that differ more then just in the irrelevant order of triples. They are representing the same data but the final form is dependent on the order of parsing the file.

3.3 *SWOP "World Assumption"*

One of the most basic decisions in any modelling endeavour is the choice of the used 'world assumption': an Open World Assumption (OWA) or a Closed World Assumption (CWA). Without going into too many formal details, we can state the following:

In case of an Open World Assumption, everything not said (stated, specified, modelled) is assumed to be "unknown", so it can still be true or false. In this case the model (ontology, schema, etc.) never forms a 'closed world': the environment is always taken into account. Nothing is assumed false when unknown because you never now someone else outside the current scope (say a modeller in Timbuktu) might state something is true or false after all.

In case of a Closed World Assumption, everything not said is assumed to be "false". In this case the model (ontology, schema, etc.) does form a 'closed world' on itself where the outside world is kind of ignored. Everything not said in this scope is per definition not true aka false.

Most traditional modelling approaches (like in e.g. ISO STEP's EXPRESS) apply a closed world assumption whereas more modern, especially web-based, approaches start from an open world assumption. In the SWOP project we make use of semantic web technologies which typically assume an open world.

A defined property in OWL is in principle a property of any class. So we have to add so-called 'domain clauses' to limit the relevance of properties to certain classes. In SWOP we assume only one class (having this property). So each user-defined property has a domain clause referencing exactly one domain class.

Subclasses are in general non-complete (their union is not spanning the whole superclass) and overlapping (or not disjunct). In SWOP however we decided for simplicity to only allow complete and disjunct subclasses. For flexibility and simplicity we decided not to model these constraints explicitly. We assume implicitly completeness and disjunctness for all subclasses for each superclass at 'configuration-time' by our software. At design-time this means one can more easily add a certain subclass when desired without changing too many rules for the relevant superclasses. We do not define a default subclass. For the PMO Configurator, the first specialisation sub class encountered (in the OWL file) is selected and displayed.

We (pre)define in PMO a decomposition object property that has the generic 'Product' class as both domain and range class. Hence, any end-user ontology class can be part of any other end-user class. For our product modelling we have to be more precise. That's why we use closures and QCRs (Qualified Cardinality Constraints) to limit the decomposition possibilities. With 'closures' we state what classes of parts are possible/relevant for a certain whole class. For those possible ones the default min and max cardinalities (as for all properties) apply, being 0 for the min cardinality and +INF(inity) for the max cardinality. We use QCRs to further constrain these cardinalities as required. For products that have no further decomposition (or "atoms") we define that the max cardinality of the decomposition property is zero (non-qualified, so for all possible qualifiers). For decomposition however we need some "default amounts" too. Adding a kind of annotation to a (qualified) restriction (min/max cardinalities) was considered too complex. Therefore, the default here is the same as the min cardinality value. Rules will affect these amounts of things (derivations or assertions will be taken into account via cardinality modifications respectively warnings). In the SWOP PMO Configurator GUI by TNO there will be a field for each qualified hasPart_directly object property indicating min and max cardinalities where an end-user can specify an actual amount in between.

3.4 *Classes*

Classes form the most basic meta concept in OWL. They are used to model the primary concepts with 'members' as their 'extension'. These classes are not 'object-oriented classes' with methods but are reflecting sets of members defined in some logical way (like by using predicates or via enumeration). The members of the classes are called 'individuals' in OWL.

It is important to note that we have to be very clear on the interpretation of classes and individuals: individuals are occurrences that exist in reality (or *could* exist if they don't exist *yet*): one can (or could) point at them, everything else is a class. This means that a catalogue item is a class of which you can order three individuals. In product modelling we typically prefer a three-level approach ('generic-specific-occurrence') involving, beyond a generic class and a particular individual, some 'variant' in between (partially or fully specified) that can be placed in space and/or time several times. In principle there are several ways of mapping the required three levels to the two levels offered by classes and individuals.

We have chosen for a way where variants are modelled as sub-classes. This is the most natural way since a variant indeed denotes a set of occurrences in the end that comply to the variant structure (just having a different placement in space or time). We can further distinguish predefined "standard" variants and on-the-fly defined 'end-user' variants.

3.5 *Properties*

Properties in OWL are a bit special for two reasons:

- They are so-called 'first class' concepts which means that they are on the same level as the Class concept. In many other modelling approaches, properties (attributes, slots, etc.) are secondary concepts: first there are entities, classes, etc. and then there are properties which are typically directly associated to such an entity, class, etc. Not so in OWL: classes and properties are considered equally important and modelled independently first and then interrelated where relevant, and
- Properties in OWL do not just denote simple (datatype) properties having a 'value' according to some data type like height, width etc. but they also cover relationships between classes. Said otherwise: if classes and datatypes are the nodes of an ontological network, the properties represent *all* the edges between them.

Let's first address the more simple Datatype Properties in OWL. For each property a domain and a range is specified. In the example below the domain is a Window so it means that only a Window can have a windowWidth property. If nothing is specified, in principle, all classes can have this property. Next a range is specified, here being the float datatype reused from the XSD name space. Besides Floats, its also possible to have Integers, Strings, Booleans or more specific ones involving times and dates. In case of strings we can enter enumerations: sets of allowed values. Interrelationships between classes are modelled similarly properties now having individuals both as domain and as range.

With the notions of classes, individuals and properties we introduced so far all main 'archetypes' of OWL modelling. In a sense, all further modelling details are forms of what OWL calls 'condition modelling'. We will first consider a very important type of condition that got its own language element in OWL: subclassing enabling class specialisation to be modelled.

3.6 *SubClasses*

Remembering that all classes represent classes of individuals it follows quite logically to be able to define subsets of individuals satisfying certain conditions. If A1 is a subclass of A it means that all individuals of A1 are also individuals of A. The subClassOf property is already predefined in the RDFS layer[1] of OWL. The same way another subclass of Product was defined: the Facade.

At design-time we assume a full open world assumption. However at configuration-time we will assume leaf classes having no further specialisation: if read in memory there is no known further specialisation. We will also always consider (implicitly) all same-level subclasses (sharing the same parent superclass) being disjunct, complete and allow only one super-class for each subclass. Finally we will always assume a choice of subclass to be made when configuring. This way we get not too complex specialisation tree structures and not too much overhead.

3.7 Cardinalities

For each property one can define minimum and maximum cardinalities, in the context of a class (in the SWOP situation: in the context of its *one* domain class). For each cardinality constraint a new, anonymous, superclass is defined representing 'all things having say a minimum cardinality of 1' (there should be at least one…) for a certain property. By making the class of interest a subClass of this class we actually express the condition that should hold.

4 PRODUCT MODELLING ONTOLOGY (PMO)

4.1 *Introduction*

As made clear in the previous section, OWL has a lot of power to model 'anything' including products. Still, there are some missing features, some of which are generic and foreseen in the upcoming OWL update 2.0 and some which are beyond the scope defined for this language. The latter are typically addressed as 'modelling patterns' to be reused as a kind of best practices as described in (W3C BP). Just as with implementation-oriented 'software patterns' we can define 'product modelling patterns' that are useful in many situations but that are not directly supported by the language (OWL).

This can be regarded as a kind of layer in between the language (OWL) and the end-user product ontologies. We are talking small, reusable ontology parts like for modelling 'decomposition', 'units', 'default values', etc. Preferably these patterns are reused from a reliable, authoritative source. Fortunately W3C formed a "Semantic Web Best Practices and Deployment Working Group" for identifying, developing and promoting such patterns. Unfortunately they don't provide all patterns needed for SWOP and some in a way that are not directly suitable.

In this section we will define a minimal set of SWOP extensions needed to fulfil the SWOP product modelling requirements identified. In the end, all these constructs are collected in some small reusable OWL ontologies that have to be imported by any end-user ontology:

- product.owl (the top-level PMO ontology),
- representation.owl,
- rule.owl, and
- operation.owl

Collectively we refer to these ontologies as the SWOP Product Modelling Ontology (PMO).

4.2 *Qualified Cardinality Restrictions (QCRs)*

With normal (unqualified) cardinality restrictions one can say something about the amount of range individuals for a specific property in the context of a specific class. In case of data type properties this is typically fine. In case of object properties there could be alternative range classes relevant. If the range its type is a superclass with say 5 subclasses; we can limit the amount to 10 individuals of type superclass but we're not able to specify in more detail with respect to which type of subclass.

QCRs add exactly this information. Instead of saying a Pizza had max 5 layers we can now express that it should have max 2 cheese layers, exactly one meat layer and one or two sauce layers. This added expressiveness is crucial in modelling product decomposition as will be explained in the next section.

4.3 *Product Decomposition*

'Decomposition' is one of the most missed OWL built-in mechanisms. One of the standard OWL abstraction mechanisms is "specialisation" using subclassing. For each class identified we can specify its superclass via a built-in "rdfs:subClassOf" property. This way we can model whole hierarchies of classes that are more or less generic/specific.

Now when specialisation corresponds to the 'logical *or*'-relationship: a vehicle is a car or a boat *or* a

[1] The layer on top of RDF that actually starts differentiating between the meta-concepts 'class' and 'individual'

plane; decomposition corresponds to a complementary ‘logical *and*’-relationship: a car consists of an engine, a chassis *and* the bodywork. Decomposition becomes a kind of orthogonal hierarchy with respect to the specialisation hierarchy.

To some, decomposition is seen as even more important than specialisation since it seems to stand ‘closer to reality’: we ‘think up’ superclasses but we ‘see’ aggregates/composites. At class level we are talking typical decomposition and at individual level we have the actual decomposition (by some referred to as ‘object trees’).

The W3C Best Practices pattern using someValuesFrom has some serious drawbacks:

– Each part always has at least one whole (some == at least one); it has no life of its own but always in the context of a whole, and
– The maximum cardinality cannot be controlled (we cannot state there is exactly one whole or ten, or less than fourteen etc.). The same is true in case of hasPart relationships if these are used (i.e. like ‘a house has exactly three bedrooms’ or ‘maximum five bedrooms’).

We can conclude that using “someValuesFrom” is not the optimal OWL mechanism. We expect much more from the yet-to-be-formally-introduced ‘Qualified Cardinality Restrictions (QCRs)’ which give us the power to control both min and max cardinalities for both directions (partOf and hasPart) in a more precise way indicating the valid target class amounts.

This new mechanism is expected to be present in the upcoming OWL2.0 update. We will now show how this powerful approach, as chosen for SWOP/PMO, works. In SWOP we will only use the hasPart_directly variant. Instead of the ‘someValuesFrom’ condition we get:

Example

```
<owl:Class rdf:ID="House">
   <rdfs:subClassOf>
      <owl:Restriction>
        <owl:onClass>
          <owl:Class rdf:ID="BedRoom"/>
        </owl:onClass>
        <owl:minCardinality
          rdf:datatype="http://www.w3.org/
           2001/XMLSchema#int">1
      </owl:minCardinality>
      <owl:onProperty>
          <owl:ObjectProperty
            rdf:ID="hasPart_directly"/>
      </owl:onProperty>
     </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

Here the ‘someValuesFrom’ is replaced by a min cardinality constraint being 1 and no max cardinality constraint (default being ‘+infinity”). So a House has 1 or more BedRooms. Note that we have to specify clearly the underlying type now being BedRoom via the new (OWL2.0) ‘onClass’ tag.

Why so much fuss about decomposition? Well, we think it is one of the most important abstraction mechanisms for modelling objects around! With a clear best practice in the OWL context and supported by tools, it can be regarded as THE approach for modelling ‘class & object trees’ complementing the built-in specialization mechanism of OWL itself.

4.4 *Meta-properties: Units and Default Values*

Being able to model that ‘the weight of this machine is 14’ does not say much. We have to indicate the unit of measurement for the value ‘14’. In a sense, we have to put this value in the right context. There are many ways to add the fact that we mean ‘14 kg’. Some initiatives put it in the value: ‘14 kg’ instead of just ‘14’. Other initiatives define a full blown unit ontology which is then related to the property and its value. In SWOP we have chosen a lightweight solution using ‘annotations’. Annotations are OWL’s way of escaping pure OWL, a means to extend OWL.

Formally annotations are just treated as meta-information not necessarily processed by OWL parsers but all signs are that they will get more importance in future versions of OWL (since meta-modelling is seen as key to more flexible modelling in general).

That’s why we decided in SWOP to use this feature for meta-data on properties, not only units but also for default values. For the current handling/visualization of ontologies (when no individuals are available yet) we use the “defaultValue" information to decide actual values for user-defined datatype properties.

Example

```
<owl:DatatypeProperty rdf:ID="facadeWidth">
    <product:unit
       rdf:datatype="http://www.w3.org/2001/XML
       Schema#string">m</product:unit>
    <product:defaultValue
       rdf:datatype="http://www.w3.org/2001/XML
       Schema#anySimpleType>5.5</product:
       defaultValue>
</owl:DatatypeProperty>
```

This way the units are modelled as meta-data at class level without the need to repeat them on individual level.

4.5 *Representation*

SWOP is primarily concerned with semantic information. Still there is a need to also handle non-semantic, representational information linked to or derived from the pure semantic information. Typically this information deals with shape aspects where implicit semantic information like height, depth and width are represented as parametric cubes, Boundary REPpresentations (BREPs) or even presented in nice (pixel-based) pictures. Unfortunately there is not one standard for expressing this information in a generic way. IAI IFC is a way of doing for the construction industry (especially for modelling 'buildings'). Another problem is the fact that such standards differ greatly in expressive power (even in this type of modelling we can distinguish different levels of smartness ranging from fully parametric explicit shape objects to simple pixels).

For this reason we decided to define a high level representation ontology ('representation.owl'). This ontology is imported by the product modelling ontology. This representation ontology is used as generic linking pin towards domain-specific representation schemes such as IAI IFC for construction. Further details with respect to representation issues in PMO can be found in (PMO 2008).

4.6 *Rules*

In the previous sections we have seen many forms of local rules or 'conditions' as they are called in OWL which are expressed within the ontology. Clearly in SWOP there is a need for several types of global rules. These rules are typically positioned above/on top of the ontology. We identify two main rules types:

- Assertions as integrity rules, that are checked/validated, and
- Derivations as Production/Action Rules, that are done/executed.

Another distinction for rules is in 'determined' or 'undetermined'. A rule is 'undetermined' if it still contains some freedom like in case of logical or-expression or numerical or-range like 'X>25'. Assertions can be 'determined' or 'undetermined'. Derivations have to be determined. Both types involve logical and non-logical (like numerical or string) binary, unary and/or nullary operations. Some more examples to clarify:

Assertions:

- wheelDiameter > (2.8 * axisDiameter)
- IF (AMOUNT[2] (PowerSupply) >= 1) THEN (safetyLevel = "1" OR "2")
- IF (AMOUNT (window) >= 3) THEN (AMOUNT (door) <= 1)

[2] 'AMOUNT' is a predefined nullary (non-logical) operation that gives the amount of individuals for a Class or Object Property. It can be used e.g. in comparisons to specify more structural rules involving a product subclass or part actually chosen, controlled by the relevant cardinalities involved.

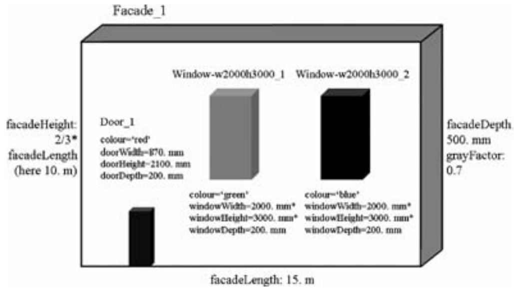

Figure 3. The intended façade.

- IF machineType = "special" THEN (bladeColour = green)

Derivations:

- windowHeight := ((2 * windowWidth) + 0.04)
- IF machineType = "special" THEN (bladeColour := green)

Again, more details on the rule mechanisms in PMO are described in (PMO 2008).

Typically the drawback of a meta-approach in OWL for rules is the tedious input process. Luckily EU project Manubuild (see chapter 5) developed a PMO Editor where you can specify the rules and their operations in a more user-friendly way and generate the actual OWL code needed.

5 EXAMPLE APPLICATIONS

5.1 *In SWOP itself*

In this chapter we will show for a, not too complex but typical, example how the SWOP Product Modelling Ontology (PMO) approach is applied. In this example object properties are not yet present. We start with a specific real life situation of a facade individual as depicted in the next figure.

Applying PMO to this example we go through the following seven typical steps:

- STEP1: Define the Ontology files/headers
- STEP2: Define the relevant Classes & Put them in a specialization hierarchy
- STEP3: Put the Classes in an orthogonal (and typical) decomposition hierarchy
- STEP4: Define the relevant (data type and object) properties for all the classes if relevant with their data types
- STEP5: Define the semantic rules
- STEP6: Define the rules for generating an IFC representation
- STEP7: Configure the typical example in the PMO Configurator: Show it for the individual we has in mind.

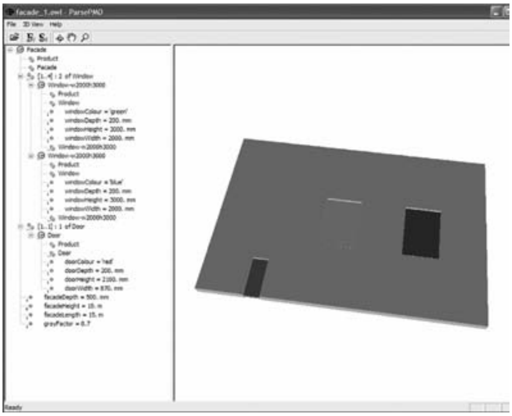

Figure 4. The configuration result.

Figure 5. Example from Saturn Engineering.

This should result in a visualization resembling the previous figure we started with…. i.e. the 'proof-of-the-pudding':

Furthermore PMO is applied to the products offered by the end-user partners within SWOP (Blum/kitchen hinges, Züblin/tunnelling equipment, Saturn Engineering/sealing cap machines and Trimek/measuring devices). In the following figure it is shown that a measuring machine's parts, properties and underlying rules are modelled and visualized via IFC.

5.2 *Use in manubuild*

In the European Manubuild IP the semantic modelling approach from SWOP was chosen as base methodology and technology. Software partner Graphisoft has made adapters to and from their proprietary Graphical Description Language (GDL). Application areas include a reference housing project by contractor Taylor Woodrow in the UK. The stair part here is a good example of how PMO can be used to model local regulations with respect to widths, heights, amount of steps etc. and to show on the fly the consequences of changed design parameters.

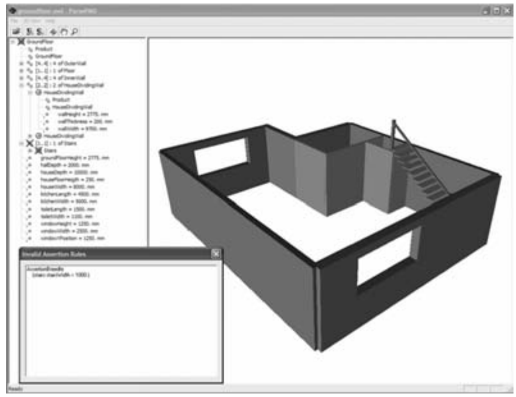

Figure 6. Taylor Woodrow's 'Wimpey House'.

5.3 *Use in InPro*

In the running European FP7 InPro IP we defined a practical combination of the IAI Information Delivery Manual (IDM) and Model View Definition (MVD) approaches. Starting with process description we identified Exchange Requirements which were grouped for domains (like 'Architectural Design', 'Energy', Cost Estimation' and 'Product Data Management', and 'Time Scheduling') and mapped if possible to existing IFC entities and types.

Things not available in IFC are now modelled as SWOP's PMO-based ontologies defining/controlling the extra proxies and properties exchanged via the meta-model part of IFC (now in a managed way since we provide back links from the meta-data to these ontologies).

5.4 *Use in IntUBE*

In the European FP7 Intelligent Use of Buildings' Energy information (IntUBE) project PMO will be used as basis for an 'Energy BIM" providing the key component of the integrating platform for a variety of energy-related software application on the scale level of buildings but also their built environment they are positioned in.

One of the partners is SINTEF, also the home of BuildingSmart approaches like International Framework for Dictionaries (IFD) and the related ISO 12006-3:2007 modelling language. Therefore IntUBE is a unique opportunity to bring SWOP PMO- and ISO 12006-3:2007-based 'camps' in line.

5.5 *Use in IOS*

In the Netherlands there has been recently set up a group called Initiative group for Open Standards (IOS). Members are leading Dutch software vendors in Architectural Design and analysis. They want to define and agree data structures for the bilateral links between their software packages in the interest of their clients. We developed especially for them the structured Microsoft Excel import capability that automatically generates PMO data structures.

We also developed for them an export to the much weaker ISO 12006-3:2007 specification that can be alternatively referenced back from an IFC model (the IFC we 100% generate for visualization of our PMO ontologies by means of the PMO rules and operations).

5.6 *Use in COINS*

In the Dutch Constructive Objects and the INtegration of processes and Systems (COINS) project their COINS BIM (CBIM) model will be aligned with PMO. CBIM will be positioned as layer around PMO, specializing our generic 'Products' root class into 'Functions', 'Spaces' and 'Physical Objects'. Also product requirements are then integrated with the 'solutions' offered by PMO.

6 FURTHER R&D

6.1 *PMO Workbench*

Currently we have separate design-time and run-time tools: the PMO Editor respectively the PMO Configurator. In the near future these tools will be integrated potentially together with built-in end-user requirements and objective into what we call a PMO Workbench. Genetic Algorithm (GA)-based services could be built in to ask to system to advice some or all input values instead of providing them by hand.

Also the construction-specific IFC-based visualization might be replaced by more generic Java3D variant.

6.2 *GIS/GIM-links*

Another extension dimension is the inclusion of higher scale levels towards Geographical Information Systems dealing with Geographical Information Models and their underlying technologies like Open Scene Graph (OSG) and COLLAborative Design Activity for establishing an open standard Digital Asset schema for interactive 3D applications (COLLADA), a currently used open standard by Google's SketchUp and Google Earth software products.

6.3 *W3C Web Services*

Our demonstrators up till now feature one supplier that, when needed, retrieved and modelled product information from his suppliers or their suppliers even further down the supply-chain. In the future when critical mass is building we foresee a situation where all data is modelled and kept up to date at the owner, only reused by others (distributed data).

Reasons like confidentially and sensitive information (prices, building element recipes, etc.) may require connecting not directly to the distributed data but via the functionalities of sub-configurators manipulating that data. In that deployment scenario web services as (sub-) configurators over the web come directly to mind.

6.4 *W3C Incubator Group on Product Modelling*

Finally, all base PMO future developments ('PMO2') will be openly harmonized in a W3C Incubator Group for Product Modelling (short name: W3pm). This group has been initiated by TNO, Fraunhofer and the POSC-Caesar Association (PCA), all members of W3C (W3pm 2008).

ABBREVIATIONS

3D – 3-Dimensional
API – Application Programming Interface
BIM – Building Information Model(ling)
BP – Best Practices
BREP – Boundary REPresenation
CBIM – COINS BIM
COINS – Constructive Objects and the INtegration of processes and Systems
COLLADA – COLLAborative Design Activity for establishing an open standard Digital Asset schema for interactive 3D applications
CWA – Closed World Assumption
FP – (European R&D) Framework Programme
GA – Genetic Algorithm
GDL – Graphical Description Language
GIM – Geographical Information Model(ling)
GIS – Geographical Information Systems
IAI – International Alliance for Interoperability
IDM – Information Delivery Manual
IFC – Industry Foundation Classes
IFD – International Framework for Dictionaries
INF – INFinity
IntUBE – Intelligent Use of Buildings' Energy information
IOS – Initiative group on Open Standards
IP – Integrated Project
ISO – International Standardization Organization
MVD – Model View Definition
OSG – Open Scene Graph
OWA – Open World Assumption
OWL – Web Ontology Language
PCA – POSC Caesar Association
PMO – Product Modelling Ontology
POSC – Petro-technical Open Standards Consortium

QCR – Qualified Cardinality Restriction
R&D – Research and Development
RDF(S) – Resource Description Framework (Schema)
SDAI – Standard Data Access Interface
SPFF – STEP Physical File Format
STEP – Standard for the Exchange of Product model data
SW – Semantic Web
SWOP – 'Semantic Web'-based Open engineering Platform
TBC – TopBraid Composer (by TopQuadrant)
W3C – World Wide Web Consortium
W3pm – WWW product modelling incubator group
WS – Web Services
WWW – World Wide Web
XML– eXtensible Markup Language
XSD – eXtensible Schema Definition language

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PMO, SWOP Semantic Product Modelling Approach, with PMO – The SWOP Product Modelling Ontology, deliverable D23, revision 8, 15 April 2008.

W3pm, W3C Incubator Group on Product Modelling, http://www.w3.org/2005/Incubator/w3pm/, May 2008.

COLLADA, http://www.collada.org/.

IAI IFC, http://www.iai-international.org/.

InPro, http://www.inpro-project.eu/.

Manubuild, http://www.manubuild.org/.

SWOP, http://www.swop-project.eu/.

W3C BP, Best Practices, http://www.w3.org/2001/sw/BestPractices/.

W3C SW, Semantic Web Activity, http://www.w3.org/2001/sw/.

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

A simple, neutral building data model

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ABSTRACT: A growing number of building simulation tools exists in France and elsewhere. These tools serve different purposes: building code compliance (RT 2005), energy performance optimization, proof of concept, etc. As a consequence, often the same actors have to input the same building into different tools. Originally (before 2007), most of the building simulation tools commonly used in France did not include any mechanisms to exchange project data. Only one tool is able to read IFC data files (a global approach aiming at connecting a huge variety of tools); the implementation of full IFC compliance is considered too complex/costly by the small editors of the other tools. In this situation, a very simple, easy-to-implement, solution has been proposed in the form of the NBDM – a Neutral Building Data Model. Much less ambitious than the IFC approach, it captures the essentials of a thermal building product model in less than 20 classes. While such 'insular' solutions could be considered against the 'IFC spirit', we feel that the introduction of such 'small scale data models' will help to better connect software tools which do not have the critical mass to support 'complete' (complex) data models, but are still critical to our industry. At the same time, such initiatives prepare a future connection of these islands to more global approaches such as the universe of the IFC data model. This approach is totally in line with the global effort of building energy performance improvement. We seek to reduce the consumption by studying several parameters (insulation, energy management, . . .) or to obtain better summer comfort conditions (solar mask efficiency, . . .) by turning independent tools in to a chain of collaborative tools.

1 INTRODUCTION TO NBDM

NBDM 1.0 is an object oriented data model which uses the XML syntax for physical project data files. Its main characteristics are:

– Covers thermal building simulation only
– No detailed geometrical model (only orientations (North, 43.5° west. . .) are given; version 1.2 added surface vectors, which are however only used for a graphical representation of the building (currently not destined for calculation)
– *Extremely* simple to describe, understand and implement (uses less than 20 classes (entities/types of objects), can be fully explained in less than 1 hour)
– Extensible (new concepts have already been successfully added since version 1 has been implemented and used)

The NBDM data model has been successfully implemented in the following major French and international building simulation tools: ClimaWin, CODYBA, COMFIE, and TRNSYS (a general simulation environment containing a detailed building model). It is currently being used and tested in real-world projects. Other links are in preparation.

2 NBDM AND IFC

In his thesis, Treldal (2008) analyzed how input and output of five simulation tools[1] can be defined in IFC or derived from IFC. The average values of data covered are respectively 42% and 28%. This means that 70% of data match directly or indirectly with the

[1] iDbuild, Riuska, BSim, Be06 and Flovent

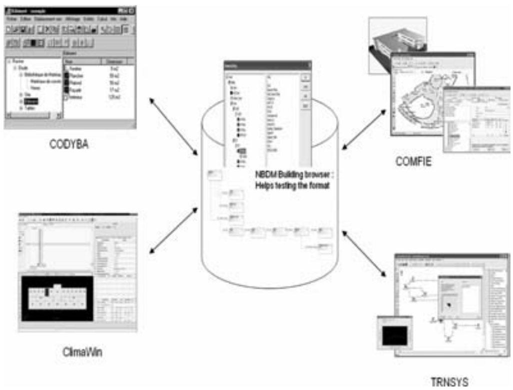

Figure 1. A very simple data model, using less than 20 classes, helped to connect France's major building simulation tools.

IFC model. 88% could be achieved creating few new property sets and adding some properties to existing property sets.

We applied the same methodology to the NBDM1 model[2]. The results are quite comparable: 42% of input/output data can be defined in IFC and 23% could be derived from it.

Without considering attributes related to shading effects, the value rise up to 80%. This is probably because the description of shading effects in the simulation tools is still drawing based. A BIM based solution should be quite different and more efficient (Bedrune et al, 1999) (ECOTECT 2007).

2.1 *NBDM 1, gbXML and IFC*

NBDM 1 and gbXML are both focused on thermal simulation, but the business need is different: NBDM 1 has been developed to share data between several tools that could be used to evaluate the same project; gbXML is a support to exchange data between CAD tools and one Web based solution capable of evaluating energy consumptions and CO2 use of the building. Archicad and Revit Architecture are proposed as add-ons to perform simulations even when the level of definition of the project is very low during preliminary design.

We consider IFC as the most promising means to exchange between the CAD Architecture tools and the simulation tools because most of these tools import IFC and the quality of the interfaces is increasing. Due to the richness of the model, sometimes editors implement different solutions to the prejudice of interoperability. For crucial points, editor's agreements have already been defined. As an issue of the IAI meetings in Tokyo on 2008 April, it is expected to harmonize the way CAD tools define space boundaries.

[2] NBDM has been derived from data exchange capabilities between the 4 following tools: Climawin, Codyba, Comfie, Trnsys

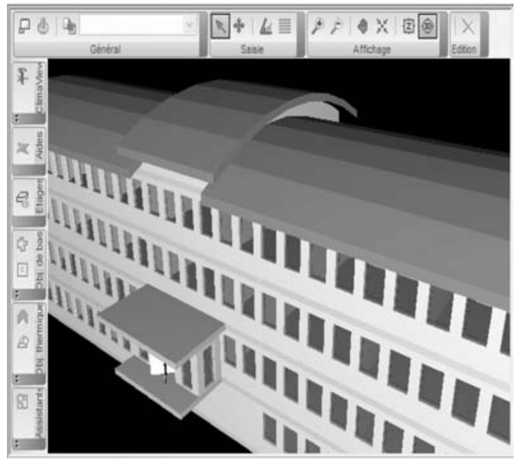

Figure 2. A CAD representation of a building in ClimaWin.

The scope of NBDM is currently limited to the description of spaces, zones and the building elements which delimit them. NBDM does not deal with equipment, and simulation hypothesis like schedules and simulation results are not exchanged.

This type of information is part both of the gbXML and IFC data models. Thanks to the BS-8 project (IAI 2001), the IFC model integrates a time series concept, convenient for schedules and simulation results, as well as the capability to describe the performance of one instance over time.

2.2 *How to bridge the gap between IFC and simulation tools*

The Climawin software by BBS provides interesting functionalities:

1. IFC import
2. Definition of zones from spaces
3. 2D and 3D viewer
4. IFC and NBDM trees viewer
5. Calculation of walls and slabs areas from data about space boundaries.
6. NBDM1 Export

Using both the IFC and NBDM 1 format, we succeeded in transferring data between CAD tools like Archicad and simulation tools like TRNSYS.. order to allow free connections between the tools exchanging through NBDM, we plan to develop a module that could act as a bridge between IFC and the future next release of NBDM.

NBDM Class	Total attributes NBDM	Information defined in IFC	Information derived from IFC	Information can not be defined in IFC	Information sometimes defined in IFC
Project	1	1	0	0	0
Building	7	4	2	1	0
Wall_Type	6	3	1	2	0
Layer	5	4	1	0	0
Window_Type	8	5	1	2	0
Zone	4	3	1	0	0
Room	4	2	2	0	0
Wall	13	3	5	5	0
Window	8	5	2	1	0
Mask	11	0	1	10	0
Architectural_Mask	4	0	0	4	0
	71	**30**	**16**	**25**	**0**
		42%	23%	35%	0%
		65%		35%	

Figure 3. Evaluation of the mapping between NBDM and IFC.

3 NBDM AND CAD TOOLS

In parallel, approaches to create direct links from existing CAD packages to NBDM are currently under way, thus providing space boundary information directly (while IFC still works on the definition of a homogenous approach between different editors). A first implementation has created an NBDM-based bridge between the CAD tool NOVA of the Swiss company PLANCAL and the Codyba building simulation tool, using NBDM – and thus between this CAD tool and all tools supporting NBDM. This work [14], conducted by J. NOEL of JNLOG in collaboration with J.-J. ROUX of INSA Lyon, gave birth to the current NBDM 1.2, which includes a simple, vector-based geometry, allowing to preserve the graphical aspect of the building description.

3.1 *Exporting CAD data to NBDM*

The Swiss based company PLANCAL develops the NOVA software suite, a global solution for building related technical computing, including both a CAD interface and computational modules. The software is based on a stand-alone CAD tool developed in-house. NOVA targets thermal consulting companies.

The company has developed a module allowing exporting CAD data to the German ROWA software, a building code tool compliant with DIN 18599. The exported data includes the geometrical description of the building envelope, the composition and the thermal properties of the walls and windows. The exported file uses XML syntax.

As the data model used in this scenario is very close to the NBDM data model, it was possible to implement a translator from the ROWA format to the NBDM format with an effort of only two man-month. The implementation should however bee seen as a proof of concept, as the data format of the ROWA tool will still evolve. The results of the first experimentations already show that this approach can be successfully used.

3.2 *Importing CAD data into CODYBA via NBDM*

In parallel to the development of the NOVA to NBDM translator, a 3D modeler has been developed by JNLOG. It is designed for quick input of simple building geometries for studies in early project phases, using a limited number of primitives. The goal of this project is to further encourage the use of the NBDM

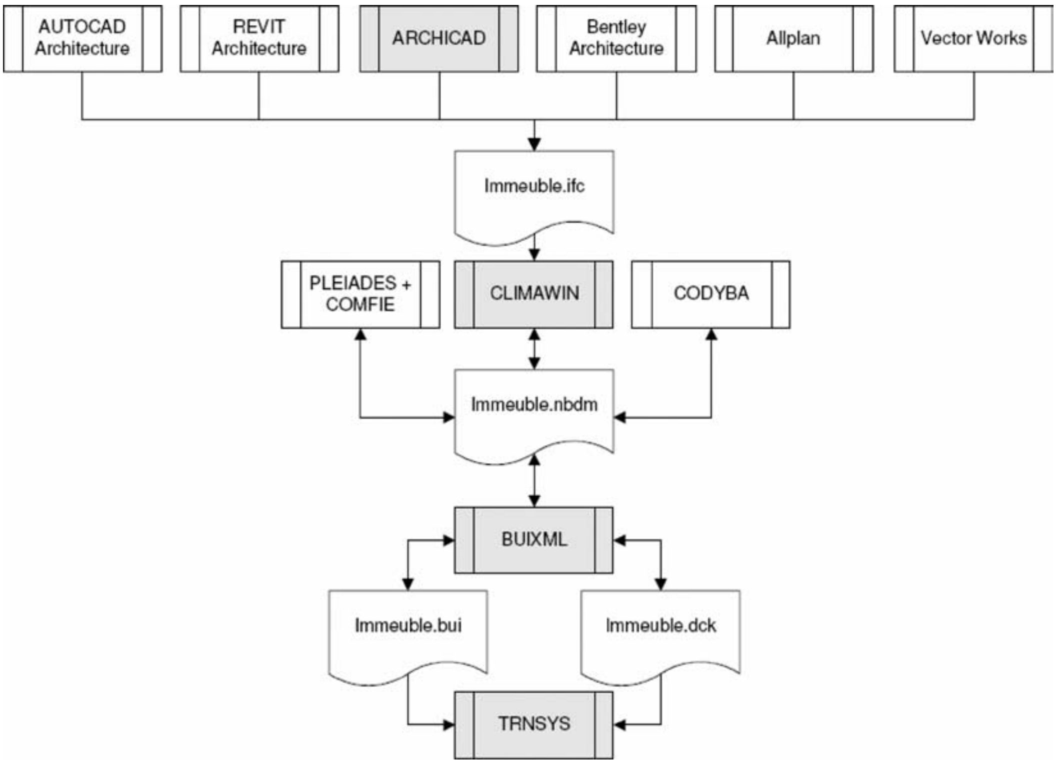

Figure 4. The path from CAD tools to simulation tools.

data model. As the implementation of 3D modelers is quite costly, NBDM allows to link up to existing CAD tools at a negligible cost – this type of tools could even be distributed for free.

4 FUTURE WORK

This article explained the scope and first applications of the Neutral Building Data Model NBDM 1.0, as well as its first extension including notions of geometry, NBDM 1.2.

Although originally conceived for thermal building simulation tools, the NBDM is a neutral data model representing a building in a quite generic way; it can be envisaged to apply it to other domains where tools operate on a similar data model (acoustics, lighting, environmental characteristics, etc.). While NBDM 1 mainly focused on the topology of the building by defining (among other things) an adjacency graph, future version should include basic notions of geometry. This need arises from the current evolution of the main building simulation tools using NBDM: while the current generation of these tools uses a very approximate notion of geometry (orientation and surfaces), the current developments aim at integrating detailed geometry (shading, self-shading, masks). At the same time, adding geometry allows for more advanced coupling with CAD tools.

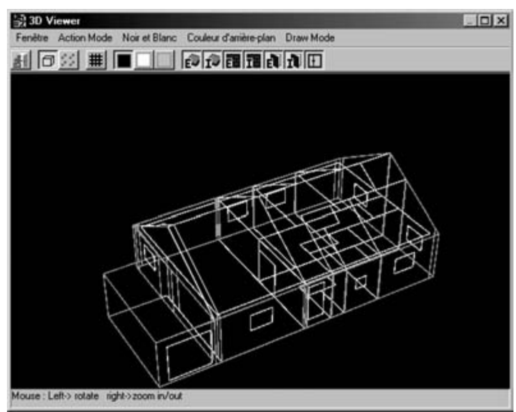

Figure 5. Example of an NBDM 1.2 file generated from NOVA data and imported into CODYBA's KoZiBu module.

The goal of NBDM 2, which is currently being drafted, should be to go beyond the logical description of adjacencies to include detailed, but neutral geometry, again in an as straightforward as possible way. The approach indeed faces the danger of gaining in complexity as new concepts are added, thus risking to loose its current main asset: the simplicity which makes it easy to understand and cheap to implement.

The data model should continue to navigate in the gray zone between the application scenarios covered by the IFC on the top end and the sheer absence of any well defined communication mechanisms at the low end. Where the IFC data model defines the SpaceBoundary concept to map geometries of arbitrary complexity, even allowing for different types of geometry (but leaving to the discretion of the software editor to actually use these attributes), NBDM must define only the essentials of a three dimensional representation of a building for simulation – but require that these attributes be used in the semantics of building simulation (an not in a generic way).

Other possible future NBDM extensions include:

- Additional connections to CAD tools and 3D building modelers
- Neutral, interoperable building element libraries/ catalogs? (windows, walls, . . .)
- Extend the group
- To more software editors
- To other types of tools
- On a European level
- Extension to include equipment (such as heating/ cooling systems)

5 CONCLUSION

While the IFC approach remains the most efficient way to exchange data between software tools, the NBDM finds its justification in the fact that it fills still existing gaps not (yet) covered by IFC – be it due to lacking implementation or specificities of the business process. Future versions of the NBDM must aim at filling these gaps, without invading the space already occupied by the IFC – indeed, once the 'NBDM glue' has filled all these spaces, it may actually in the distant future merge into the IFC data model.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

SAR design with IFC

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ABSTRACT: This paper reports a study where IFC based building models were utilized in the evaluation of "adaptability" issues of dwelling layouts in an educational context. The first part of the study discusses a workshop on the CAD implementation of the SAR design methodology, which was popularized in Netherlands in the post-WW2 era, to increase the adaptability of residential dwellings. The second part of the study focuses on the use of IFC based building models to automate the preparation of the SAR taxonomy explained in the workshop. The primary objective of using IFC in this study was to explore the potential use of this maturing technology in design research education.

1 INTRODUCTION

1.1 *SAR method*

Adaptability of floor layouts has become a vital issue in the design of residential construction in Istanbul, just like other densely populated cities such London or New York as the lifestyle changes regarding technological and social change reinforces the drive to modify house plans (West & Emmitt 2004).

A great majority of urban dwellings in Istanbul are mid-rise reinforced concrete buildings built in the 70s and 80s to accommodate the rapid increase in population. Most of these structures were poorly constructed and will need to be replaced in the next decade as they are nearing their service life. The challenge before architects will be to design a new generation of urban dwellings that can adapt to lifestyle changes of their inhabitants.

Dutch architects faced a similar challenge in the postwar reconstruction era. Standardized mass housing plans developed by the professionals and government authorities as a solution to overcome the housing shortage met with strong opposition from the people whom they were designed for. Foundation of Architect's Research (SAR – Stichting Architecten Research) was established in 1964, under the leadership of John Habraken, to investigate ways to deal with the problems of design and construction of mass housing.

In the year 1965, SAR released the report "SAR-65" which was based on the concept of "support structures" described in Habraken's seminal work: "Supports, an Alternative to Mass Housing" (Habraken 1961). Habraken argued that the uniformity of the mass housing plans could be overcome by involving the inhabitants in the design of their dwelling (Moatasim 2005).

In his work, Habraken pointed out that a dwelling needs to be considered as a system of "support structure" and "infills" each of which should be considered seperately.

Support structure or "base building" accomodates and limits the infill. Design of the support structure is essentially project oriented and shaped in accordance with the communal and infrastructural demands. The detachable "infills", which can be bought and fitted out into the support system, provide the inhabitants a more participative role in the design of their dwellings by allowing them to customize the floor layout of their dwelling according to their needs (Cuperus 2001). By this, residents of stacked multi-family dwellings would be able to transform their homes without affecting their neighbors.

In this sense, the dwelling should be viewed as a process which allows the inhabitants to make decisions according to their individual while respecting the larger framework of communal services and infrastructure (Moatasim 2005).

Support structures and infill components would be supplied by two independent industries, to benefit the most from industrialization. A grid system structure was introduced by SAR to facilitate modularization and to meet the need for positional coordination caused by the distinction of support and infill producers. The grid system used in SAR design methodology was closely related to four levels of scale, each of which was associated with a particular group of designers, decision-makers and stakeholders. The levels of scale and their respective grid spacings are presented in Table 1 (De Vries & Achten 2002).

Table 1. Levels of scale and grid spacing in SAR theory (De Vries & Achten 2002).

Level	Plan	Grid
Infill	Floor plan,. Cross section, etc	30 cm
House	Floor plan, Cross section, etc.	e.g. 90 cm (3 × 30 cm)
Building block	Street layout, etc.	e.g. 180 cm (2 × 90 cm)
Urban Tissue	Urban Plan	e.g. 1080 cm (6 × 180 cm)

In order to make sure that the design of the support structure allows for maximum variability of floor layouts, infill possibilities for support structures were systematically researched by creating a taxonomy of possible floor layouts according to the position of more permanent components of structures, such as stair-cases.

Extensive information regarding the SAR initiative and design methodology can be obtained from (Habraken 1999), (Habraken 2008) and (Hoogstraten et al. 2001).

2 SAR WORKSHOPS

2.1 *SAR Workshop with CAD*

Although the support-infill concept did not have the intended impact on the building industry, separate evaluation of the permanent and detachable components of a dwelling is quite a useful concept for adaptability studies.

A workshop was organized with the TU/e (Eindhoven Technology University), which is closely associated with development of the SAR methodology, to provide the architectural design students at IKU (Istanbul Kultur University) with the essential theoretical and practical knowledge on the SAR design.

SAR design workshop took place at the CAD lab of Istanbul Kultur University on December 13, 2007 under the supervision of Professor Bauke De Vries (TU/e), Emrah Turkyilmaz (IKU) and Gokhan Yazici (IKU). Nearly 30 architecture students participated in the event in two sessions. The central aim of the workshop was to introduce the CAD implementation of the SAR design methodology to the third year architecture students.

Students were initially briefed on the SAR methodology and the tasks they are about to perform through the course of workshop. The first task of the students was to prepare infill and support system layouts for a typical 2-story Dutch dwelling for four people (Fig. 1). Due to time constraints the students were only asked to design the infill layout of the ground floor, including the kitchen, the living room, the bathroom and the partition walls. Students downloaded the base floor plan file, which contained the layout of the structural walls of the structure, from the TU/e server.

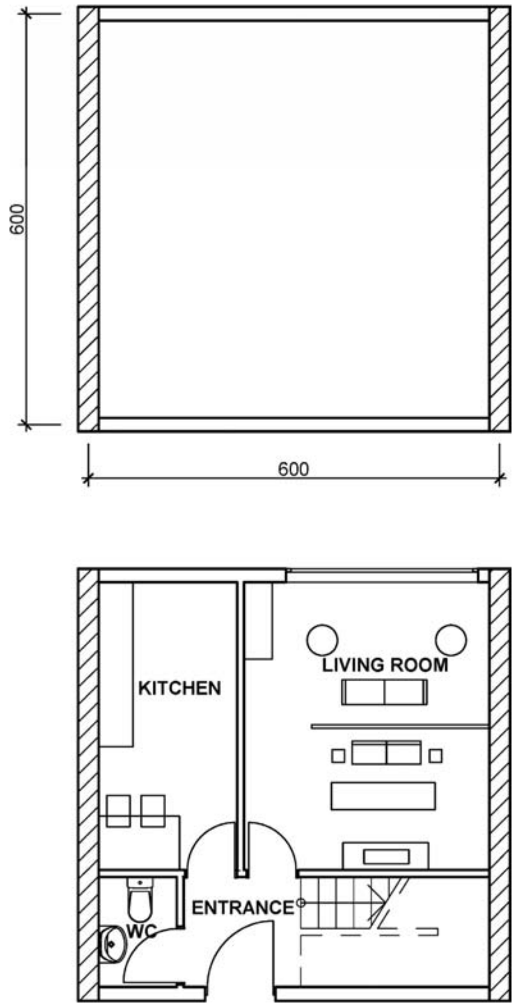


Figure 1. Given floor layout and a sample infill design.

The base floor plan file was in DWG format and had a predefined grid setup at 30 cm intervals in accordance with the SAR grid system. Students submitted their floor layout designs to the CAD server after one hour.

The second task was to prepare taxonomy of designs which commenced after the individual designs of all participants were assembled into a single DWG file. Students were given 20 minutes to prepare their taxonomy based on the layouts of the support systems.

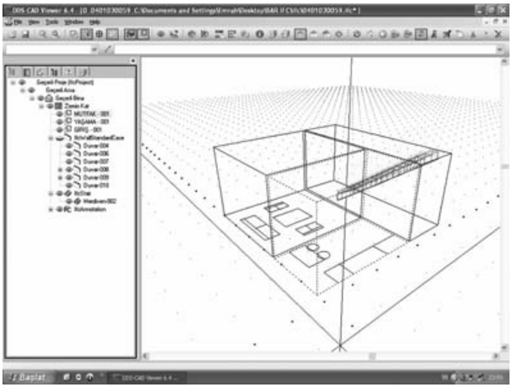


Figure 2. IFC viewer interface.

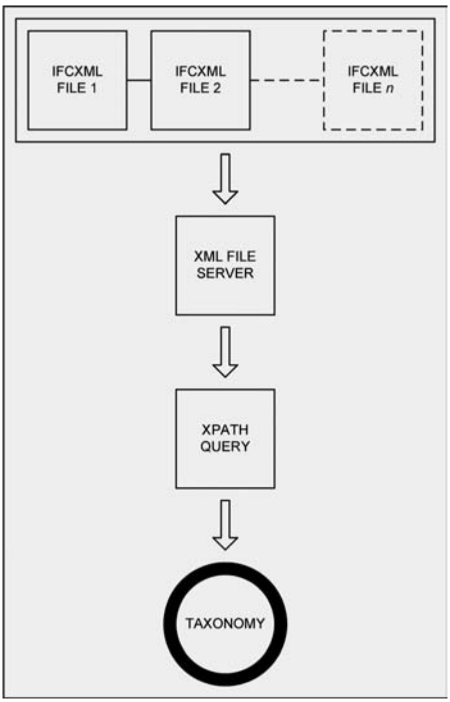


Figure 3. Using XPATH and XML file server.

Workshop ended with a discussion of the taxonomies and their implications on the “adaptability” of designs.

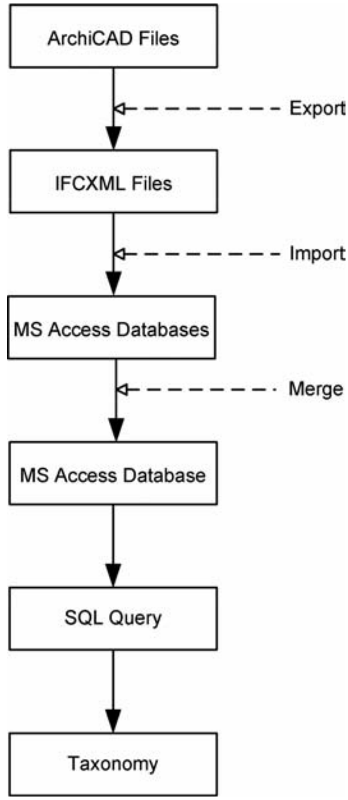
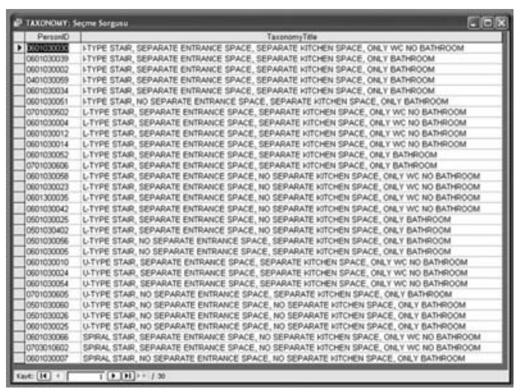


Figure 4. SAR design taxonomy with IFC.



TAXONOMY: Seçme Sorgusu

PersonID	TaxonomyTitle
0601030030	I-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030039	I-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0601030002	I-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0401030059	I-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0601030034	I-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0601030051	I-TYPE STAIR, NO SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0701030502	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030004	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030012	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030014	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030052	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0701030606	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0601030058	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030023	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601300035	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030042	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0501030025	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY BATHROOM
0501030402	L-TYPE STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY BATHROOM
0501030056	L-TYPE STAIR, NO SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
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0601030054	U-TYPE STAIR, SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0701030605	U-TYPE STAIR, NO SEPARATE ENTRANCE SPACE, SEPARATE KITCHEN SPACE, ONLY BATHROOM
0501030060	U-TYPE STAIR, NO SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY BATHROOM
0501030026	U-TYPE STAIR, NO SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY BATHROOM
0601030025	U-TYPE STAIR, NO SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY BATHROOM
0601030066	SPIRAL STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0703010602	SPIRAL STAIR, SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY WC NO BATHROOM
0601030007	SPIRAL STAIR, NO SEPARATE ENTRANCE SPACE, NO SEPARATE KITCHEN SPACE, ONLY BATHROOM

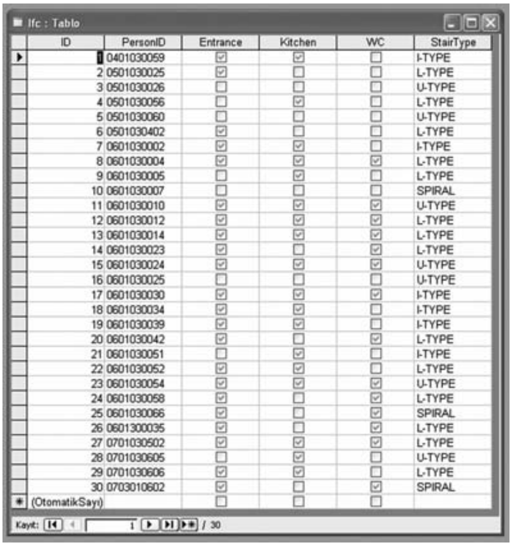
Kayıt: 1 / 30

Figure 5. Textual representation of the design taxonomy.

2.2 *SAR Design with IFC*

The use of CAD’s drafting capabilities and grid system considerably facilitated the production of design alternatives and design taxonomies.

However, grouping and evaluating design alternatives according to criteria other than the position of the support structures can be a tedious task when the number of design alternatives increase. Therefore, it was deemed necessary to explore ways to automate the preparation of design taxonomies by filtering alternatives that conform to designer’s grouping criteria.



ID	PersonID	Entrance	Kitchen	WC	StairType
1	0401030059	☑	☑	☐	I-TYPE
2	0501030025	☑	☐	☐	L-TYPE
3	0501030026	☐	☐	☐	U-TYPE
4	0501030056	☐	☑	☐	L-TYPE
5	0501030060	☐	☐	☐	U-TYPE
6	0501030402	☑	☐	☐	L-TYPE
7	0601030002	☑	☑	☐	I-TYPE
8	0601030004	☑	☑	☑	L-TYPE
9	0601030005	☐	☑	☐	L-TYPE
10	0601030007	☐	☐	☐	SPIRAL
11	0601030010	☑	☑	☑	U-TYPE
12	0601030012	☑	☑	☑	L-TYPE
13	0601030014	☑	☑	☑	L-TYPE
14	0601030023	☑	☐	☑	L-TYPE
15	0601030024	☑	☑	☑	U-TYPE
16	0601030025	☐	☐	☐	U-TYPE
17	0601030030	☑	☑	☑	I-TYPE
18	0601030034	☑	☑	☐	I-TYPE
19	0601030039	☑	☑	☐	I-TYPE
20	0601030042	☑	☐	☑	L-TYPE
21	0601030051	☐	☑	☐	I-TYPE
22	0601030052	☑	☑	☐	L-TYPE
23	0601030054	☑	☑	☑	U-TYPE
24	0601030058	☑	☐	☑	L-TYPE
25	0601030066	☑	☐	☑	SPIRAL
26	0601300035	☑	☐	☑	L-TYPE
27	0701030502	☑	☑	☑	L-TYPE
28	0701030605	☐	☑	☐	U-TYPE
29	0701030606	☑	☑	☐	L-TYPE
30	0703010602	☑	☐	☑	SPIRAL
(OtomatikSayı)		☐	☐	☐	

Figure 6. Query results of IFC database.

Filtering and grouping of architectural design alternatives can only be achieved if the design files store information on building components in a database format. Therefore, DWG models which were used to store non-attributed geometrical data in the first workshop were abandoned in favor of IFC models in the second workshop.

Industrial Foundation Classes (IFC), developed by International Alliance of Interoperability (IAI) in 1997 was chosen as the basis for the building information database in order to exploit the advantages provided by intelligent building elements and to ensure interoperability between CAD based applications.

Hence, individual designs created in the SAR workshop were initially transferred to an IFC compliant CAD application (ArchiCAD). Students were then briefed on the IFCXML structure with the help of the data files generated by the CAD application.

Afterwards, students used the DDS-CAD IFC Viewer application to observe the effects of various parameters and to achieve a working understanding of the IFCXML structure (Fig 2).

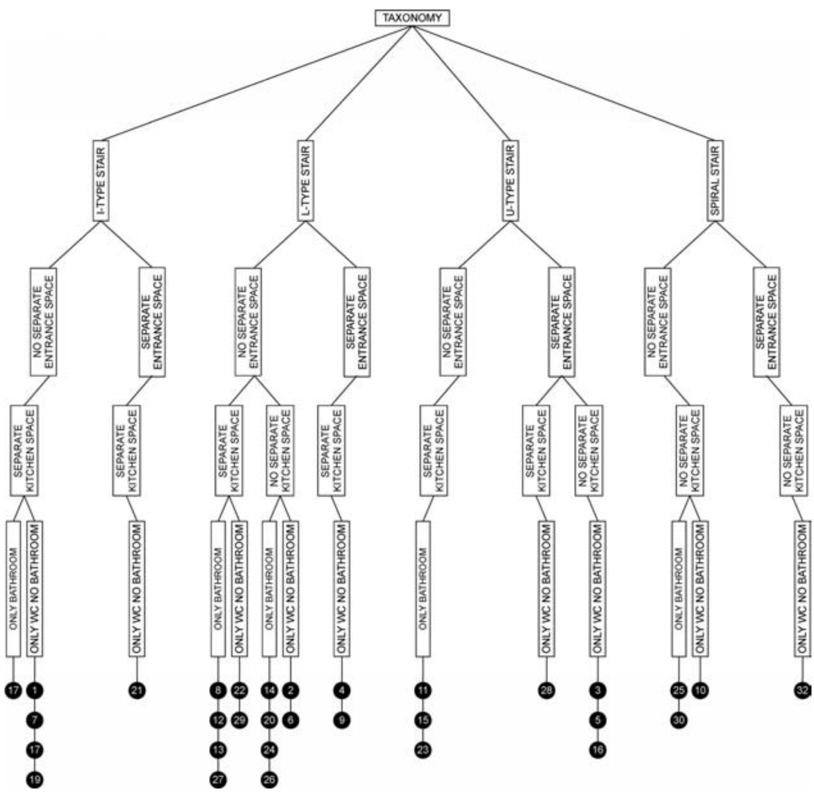


Figure 7. Graphical representation of the taxonomy.

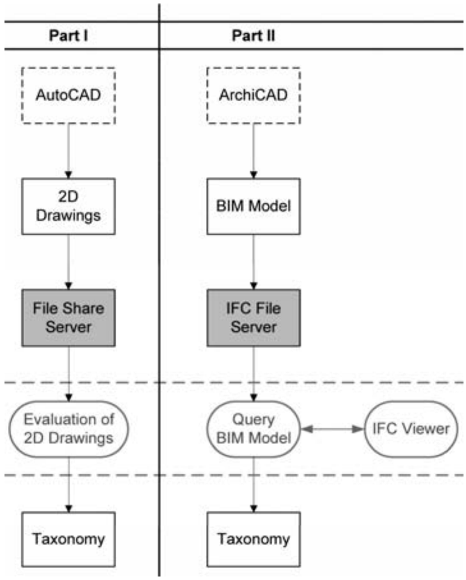


Figure 8. SAR design taxonomy with CAD and IFC.

Next step in the workshop involved querying the building information models to obtain the taxonomy. There were two ways to automate the taxonomy. First option was to create a file server to store the IFCXML files which would be queried with XPATH commands to obtain the taxonomy (Fig. 3).

Second option was to use SQL queries to obtain the taxonomy (Fig. 4). First option was aborted since it required elaborate code development which would be too difficult for the architectural students participating in the exercise.

Using the second approach, students imported their IFCXML files into an MS Access database. Afterwards, individual MS Access database files have been merged into single database file which has been queried by using SQL in order to obtain the final taxonomy (Figs 5, 6 & 7).

At the end of the session, a group discussion was held on the advantages and challenges of using IFC technology in SAR design research.

3 CONCLUSION

First workshop concentrated heavily in teaching the theoretical foundations and practical applications of the SAR method for the design of adaptable dwellings. In this workshop, taxonomy of design alternatives was manually created with respect to the positions of the more permanent components of the dwelling such as the staircase and the kitchen space. CAD drafting tools and grid significantly facilitated the drafting of design alternatives.

Second workshop focused on exploring ways to automate the preparation of the design taxonomy. Although the approach used in the first workshop was quite adequate for preparing the taxonomy and understanding the basics of SAR design methodology, preparing an interface that automates the taxonomy generation by accessing and evaluating building data from a database allowed the students to understand the fundamental concepts of BIM through hands-on practice. A general overview of the processes involved in both workshops is illustrated in Figure 8.

Although, understanding the database structure of the IFC based building models and preparing queries proved to be a challenging task for the less technically savvy students, it was observed that IFC technology can be an invaluable asset for design research and that IFC models give a better insight for developing design taxonomies compared to 2D drawings.

Another desirable aspect of using IFC based models in SAR design that surfaced in the group discussion was the capability to include the technical expertise of mechanical, electrical and structural engineers in decision-making processes which make it possible to assess technical aspects of design alternatives.

Furthermore, group discussions also revealed that design students began to develop an understanding of the type of information required for a building model in order to support collaboration which is one of the most important challenges in incorporating the IFC technology in design education (Plume & Mitchell 2007).

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Using geometrical and topological modeling approaches in building information modeling

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ABSTRACT: This paper presents concepts for dealing with topological information in building information models. On the one hand, it shows how to derive topological relationships from "traditional" building models consisting of unconnected B-Rep bodies by means of geometric processing algorithms. On the other hand, it discusses the capabilities of topological building modeling based on relational complexes, an approach based on Algebraic Topology and the Relational Data Model. To make these complexes suitable for building modeling it was necessary to extend them by geometric properties. Finally, the paper depicts an advantageous application of cell complex-based modeling: the separation of the building model into an abstract specification of building entities (sketch), a collection of possible concrete realizations of such sketch entities (details) and a specification of the details used by sketch entities. Then a working drawing results from the spatial version of the relational operator *inner equi-join*, the so-called *fiber product*.

1 INTRODUCTION

In building and construction planning one often has to deal with information along the lines of "Which elements are connected together?" or "How are different parts separated?". In floor plan layout, for example, such connectivity information can describe the accessibility of rooms within an office or an apartment as well as describing which room lets in daylight, as this calls for connectivity between the room in question and the area outside the building. Structural analysis also requires information on the structural elements that are joined together and the joints employed in the process.

Such connectivity information is a topological property of a building, and we will later see, that it may even be called *the* topology of a building. A topological space can informally be described as a set of elements together with a specification of which element is "close to" some other elements. Then a mapping from one such space to another is called *continuous*, if the image of a point "close to" some set remains "close to" the image set and is accordingly not torn off the latter. Typical examples of such a continuous mapping are the affine transformations in the Euclidean space with its so-called natural topology. If such a continuous mapping has a continuous inverse, this mapping is called topological isomorphism or homeomorphism, for short. A typical homeomorphism is an invertible affine transformation such as translation, rotation or shear. Note that under a homeomorphism the image of an element "not close to" some other elements is "not close to" their image either. The original space and the image space are then indistinguishable with respect to this "closeness" relation and is hence called topologically equivalent or homeomorphic.

Topological relationships between building components define the basic functionality of the building (e.g. its structural system, the connectivity of rooms) and knowledge about them can be used for a wide number of analytical tasks (evacuation simulation, building performance analysis, etc.). A dividing wall between two interior rooms, for example, has different thermal requirements than a dividing wall between an interior room and the space outside the building. So there is a good reason for topological properties to show up in building product models and, indeed, every noteworthy such model like RATAS, COMBINE or IFC deals with this kind of information (Bjoerk 1992, Dubois et al. 1995 & Adachi et al. 2003). It is, however, difficult to access topological information in building product models as, generally speaking, many different approaches towards modeling topology coexist within one model.

With this heterogeneity of data types it is difficult to develop applications which have to navigate within this space of interconnected entities in order to perform thermal or structural analysis or other aspects of the building's performance (Romberg et al. 2004 & van Treeck and Rank 2007). There is yet another topological structure within a building product model: the data structures used to describe the geometric representation of each building element. These structures are often defined by boundary representation (b-rep) techniques using primitive geometric entities like *point*, *edge* and *face* together with connectivity information between these primitives, hence a topology for them, too.

This connectivity information, however, is only local to the specific geometric entity, which is therefore isolated from other entities in terms of b-rep connectivity. So topological relationships between building elements must either be derived from their geometric shape or stored explicitly in the building model. The realization of these diverging approaches is discussed in the following sections.

2 THE GEOMETRICAL APPROACH

What we refer to here as the "geometrical approach" involves building models which considers a building a compilation of geometric objects located in 3D space. Each of these objects has a connected and compact geometrical shape which is described using established techniques from solid modeling such as constructive solid geometry (CSG), swept representations or the particularly interesting boundary representation (b-rep) techniques (Mäntylä 1988). So far, our approach complies with how CAD systems and common product models such as IFC or CIS/2 handle building geometry today. But, whereas in product models topological relationships between geometric objects are meant to be explicitly stored, we propose to derive them from the objects' geometry and their relative position to each other.

2.1 *Specification*

In (Borrmann & Rank 2008) a method is presented that makes it possible to query pairs of building elements with regard to their topological relationships. The topological relationships that are supported are *within*, *contain*, *overlap*, *touch*, *equal* and *disjoint*. Each of the predicates is formally defined by means of the 9-Intersection Model (9-IM), a model that was originally developed for 2D-GIS (Egenhofer 1991) but can easily be applied to 3D-BIM. It records the intersection between the interior, the boundary and the exterior of both objects in a matrix. Let A and B be point sets that describe a spatial object in 3D. Then the 9-IM matrix reads

$$I = \begin{pmatrix} A^\circ \cap B^\circ & A^\circ \cap \partial B & A^\circ \cap B^- \\ \partial A \cap B^\circ & \partial A \cap \partial B & \partial A \cap B^- \\ A^- \cap B^\circ & A^- \cap \partial B & A^- \cap B^- \end{pmatrix} \quad (1)$$

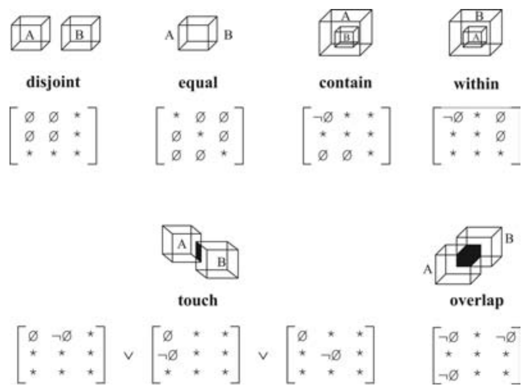

Figure 1. Some topological predicates according to the 9 intersection model.

where A° denotes the *interior*, ∂A the *boundary* and A^- the *exterior* of A. Permitted entries of the matrix are the empty set (Ø), the non-empty set (¬Ø) and the asterisk (*), the latter meaning that the respective place in the matrix is not decisive for assigning the topological predicate to a certain constellation.

Figure 1 shows the 9-IM matrices of all six defined topological predicates. The predicates are *mutually exclusive* and *complete* in the sense that, for any conceivable constellation, precisely one of the predicates can be applied. This allows one to offer the function *whichTopoPredicate* that returns the respective predicate for any given constellation. This function and the individual predicates are provided as operators for use in theWHERE part of a SQL query (Borrmann 2007).

By using the resulting Spatial Query Language it is possible to find all walls touching a certain slab, the heating equipment within a certain room or gas lines crossing a specific wall, for example.

2.2 *Implementation*

As stated above, the topological relationships between the building elements are not expected to be explicitly stored in the 3D building model. Instead, they are generated/tested on-the-fly during the processing of a spatial query on the basis of the explicit geometry of the respective building elements.

For the implementation of these topological tests we developed two approaches: the first approach is based on octree representations of the operands which are generated on demand. The resulting octrees are traversed synchronously in a breadth-first manner. On each level pairs of octants are created with one octant originating from object A and one octant from object B, both basically covering the same sector of the 3D space. Each octant provides a color combination for which specific rules can be applied. These rules may lead to filling a 9-IM matrix that is maintained to keep track of the knowledge gained by the algorithm about the topological constellation.

In total, there are 12 positive and 9 negative rules. A positive rule can be applied when a certain color combination occurs, and a negative rule if certain color combinations do not occur over an entire level. Positive rules lead to *non-empty set* entries in the matrix, negative rules to *empty set* entries. The 9-IM matrix is successively filled by applying these rules for all octant pairs. Each time a new entry is made, the matrix is compared with the matrices of the formal definitions (Figure 1). As soon as it corresponds completely to one of the pre-defined matrices, the recursion is aborted and the algorithm returns the respective predicate. If there is any divergence between the filled matrix and the matrix of a predicate, the respective predicate is precluded. If no unequivocal decision is possible for any of the predicates, a further refinement is necessary.

Our second approach for testing topological relationships works directly on the boundary representation of the building elements. To accelerate the processing of the tests, the facets describing the objects' boundaries are hierarchically managed by means of a so-called *Axis Aligned Bounding Box* (AABB) tree (van den Bergen 1997). The algorithm performs an initial intersection test to find out whether the objects *overlap*, or not. Using the AABB tree most of the facet pairs can be excluded from detailed investigation, meaning an exact intersection test only has to be performed for a limited set of final pairs.

If the *overlap* test fails, additional tests have to be performed which are based on sending out rays from one object and counting the number of intersections of the ray and the second object. Due to the limited space available, we cannot discuss the algorithm in more detail here.

Both approaches are able to retrieve topological information from purely geometrical models. While the b-rep-based algorithm is normally considerably faster, the octree approach allows for a fuzzy treatment of topological relationships by choosing a suitable maximum refinement level. This is especially interesting as we have to be aware of impurely modeled building models where slight gaps between building elements occur without intention.

3 THE TOPOLOGICAL APPROACH

The topological approach, on the other hand, is based on the formal theory of *Algebraic Topology* which requires the digital building to be modeled according to what is known as a cw-complex, where the topology is explicitly stored and does not need to be computed.

3.1 *Related work*

Using the Algebraic Topology for modeling buildings has already been proposed by a number of researchers, e.g. in (Huhnt and Gielsdorf 2006; Clemen and Gielsdorf 2008). However, the potential of this formal approach with respect to concrete applications has not been fully developed so far. In the context of 3D Geographic Information Systems (GIS), simplicial complexes have been employed to model soil layers, for example (Breunig et al. 1994, Pilouk 1996 & Shi et al. 2003). Simplexes are a generalization of closed, filled triangles and are often used instead of cells to set up a so-called simplicial complex. These are, however, very restricted and demand a costly partitioning of building elements into tetrahedra. We therefore propose using cells, the more general version of a topological primitive.

3.2 *Cell complexes*

We start with the observation that a building resides in the Euclidean space, in such a way that the latter is somehow divided into a finite number of parts by the former. The difference with the topological approach is that these parts need not be compact and that they lead to a complete *partitioning* of the Euclidean space: every point in space belongs to exactly one unique building part, a room or the exterior space. Note that hierarchically aggregated spatial objects cannot be expressed with only one such partitioning.

This partitioning immediately leads to a topology for the building elements, which is called *final topology* or *quotient topology*. This is *the* topology of a building mentioned above.

3.2.1 *Architectural complexes*

From a theoretical point of view, the statement that the Euclidean space is finitely partitioned by architecture is still too weak. We say that every building part can also be further subdivided into a finite number of cells which set up a special case of a topological space with interesting algebraic properties. It is the so-called cw-complex—a composition of cells frequently used in *Algebraic Topology* (Hatcher 2002).

An *n-cell* (cell of dimension *n*) is a topological space which is homeomorphic to the interior of an *n*-dimensional cube. For the special case of $n = 0$ we say a 0-cell is a space with exactly one point.

Low dimensional *n*-cells are often called *topological primitives* in volume modeling. A 0-cell is also called *vertex*, "1-cell" is a synonym for "edge", 2-cells are "faces" and 3-cells are also called "volumes". Figure 2 shows the canonical cells found in a closed cube. It is important, however, that a cell's boundary is never part of the cell.

Now these cells can be combined to form a topological space which is called cw-complex. This is a topological space partitioned into a set C of cells where the boundary of each cell is a union of a finite number of cells in C of strictly lower dimension than n. We always assume C be finite.

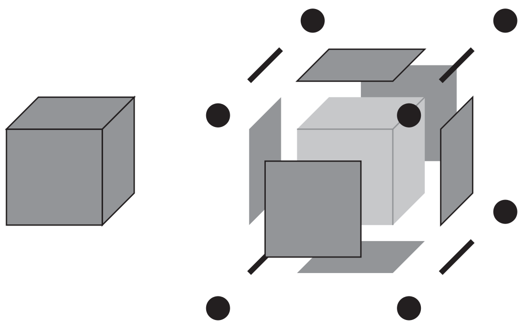

Figure 2. The canonical cellular decomposition of a closed 3d-cube.

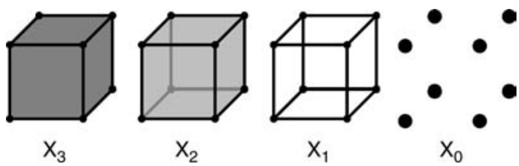

Figure 3. The skeletons of the canonical cw-complex of a three-dimensional closed cube, beginning with X3 on the left and ending with X0 to the right. Note that Xn = X3 for all n ≥ 3 and Xn = Ø if i is a negative integer.

Then for some integer number i, the set $X_i \subseteq X$, the union of $C_i \subseteq C$ of cells of at most dimension i is called i-skeleton of X. This is also a cw-complex with partitioning C_i. Each i+1-cell is also said to be *attached* to the i-skeleton. Note that i may even be negative, in which case X_i=Ø.

The 0-skeleton is simply the discrete vertex set (or point cloud) and the 1-skeleton is a graph, where the edges are attached to the vertices. Attaching faces to the 1-skeleton can be done by either filling loops or by creating cavities and gives rise to the 2-skeleton (a sponge-like structure) which is then completed to form the 3-skeleton by filling cavities with volumes. Theoretically, attaching a volume could also create hyper-cavities, but we will refrain from that. Note that, if one neglects the rooms of a building, it also displays a "sponge-like structure". Note also that a single b-rep volume model is likewise a cw-complex.

3.2.2 *Complex based modeling*

At the most detailed level, the building elements are cells which are basically the same objects used in b-rep volume modeling. Only the 3-cell as a "primitive" is missing in some of these models which mostly identify a volume with its boundary instead of providing it as a separate primitive.

We *attach* volumes to faces instead of such identification and will therefore model the connectivity information in a different way. Later the notion of a cell will be relaxed and walls or slabs can be considered faces by simply disregarding their relatively small thickness.

We will now proceed to describe a relational schema for an algebraic complex. It is a well-known fact that each cw-complex has an associated algebraic complex of this kind.

3.3 *Relational complexes*

Cw-complexes are often defined by specifying an inductive procedure of starting with the 0-skeleton X_0 and then attaching i+1-cells to the i-skeleton until the complex is finished (Hatcher 2002).

We will repeat this inductive procedure with an example volume element, a closed unit cube of dimension 3, and, in parallel, give a relational representation of the associated algebraic complex to illustrate the notion of a *relational complex* (Paul 2007). We only present here what we call the dynamic version of a relational complex, where all cells are stored in one single table together with an attribute to indicate the dimension.

We start with our specimen cube's vertices and establish the 0-skeleton as a relation with the schema

`CELLS(id:ℤ, dim:ℤ)`

with primary key {`id`, `dim`}.The coordinates of these cells set up another relation of schema

`COORD(id:ℤ,dim:{0}→ x,y,z:ℝ)`

We indicate the primary key by an arrow pointing from the primary key attributes to all other attributes. The attribute `COORD.dim` is constantly the integer 0 and only used to establish a reference to `CELLS`. We call each entry in `COORD` a *point* and each entry in `CELLS` with `dim` = 0 a *vertex*. Each point must reference a vertex.

So by simply storing the eight vertices and points in the corresponding relations we obtain the 0-skeleton of our specimen cube.

Now we have to paste edges to vertices. This will be done by adding records with a `dim`-value of 1 to the cells table and calling these records *edges* or 1-cells. To be able to attach these cells to vertices we finally define our last additional relational schema

`BD(a,dimA, b,dimB → alpha:ℤ)`

where `(a,dimA)` and `(b,dimB)` are references to `CELLS`. We will call this relation the boundary relation.We also insist on `dimA>dimB` for all entries in the boundary relation and, in addition, if these dimension attributes differ by more than one, the *alpha* value must be zero.

Note that `BD` defines a partial integer matrix D, which maps some pairs (e,v) of cells to an integer D(e,v) and is undefined for others. To obtain a total matrix, all undefined entries can be regarded as zero

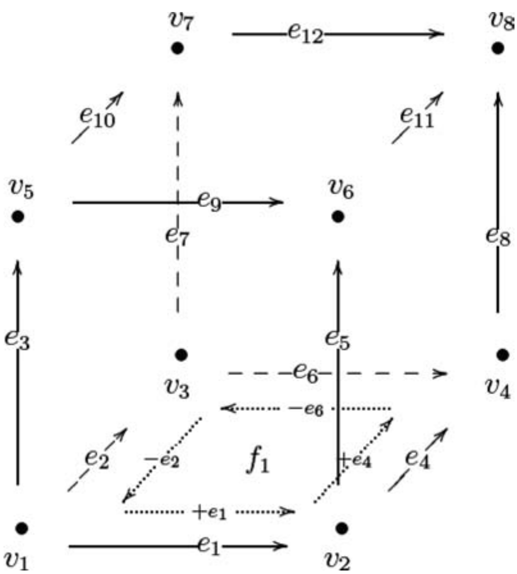

Figure 4. The 1-skeleton of a cube consists of vertices and edges. A label vi stands for cells tuple (i,0), ei for (i,1) and f1 for (1,2).

CELL		BD				
id	dim	a	dimA	b	dimB	alpha
1	0	1	1	1	0	−1
2	0	1	1	2	0	+1
...		2	1	1	0	−1
8	0	2	1	3	0	+1
1	1			...		
2	1	12	1	7	0	−1
...		12	1	8	0	+1
12	1					

entries. Each edge *e* of our cube running from vertex *a* to vertex *b* will now be stored as one record (*e*,1) in the cells relation and two additional records (*e*,1, *a*,0,-1) and (*e*,1, *b*,0,+1) in the boundary relation, indicating that edge *e* (of dimension 1) starts at vertex *a* (of dimension 0) and ends in *b*. The orientation of each edge can be arbitrarily chosen and, in our example, we simply let an edge run from lower id to higher id. This produces a 1-skeleton, displayed in figure 4 with the following boundary relation (some entries have been omitted):

This is simply the well-known incidence matrix of a graph, an approach which at first glance seems a verbose and inefficient way to store a directed graph.

Note, however, that firstly the usual way of storing such a graph as a relation with schema

`EDGE(edgeId → origin, target)`

only changes the storage complexity by a constant factor and, secondly, the advantages of our approach will become evident in the following section.

We will now paste faces to the 1-skeleton to achieve the 2-skeleton—the shell covering the cube's volume. Starting with the bottom face f_1 of our example in figure 4, we store it as a 2-dimensional cell—a record (1,2) consisting of cell number 1 and dimension 2. Then we observe that this cell is bounded by the edges e_1, e_4, e_6 and e_2, the orientation of which is, as we remember, arbitrarily chosen. As with the edges, we define an arbitrary orientation of the face, say counter-clockwise when seen from above, and then "correct" the orientation of the edges in relation to the face so that they are all pointing in a counter-clockwise direction. This is achieved by attaching a positive or negative sign to each edge indicating whether this edge has the desired orientation of the faces or whether it is pointing in the opposite direction. This produces *signed edges* $+e_1$, $+e_4$, $-e_6$ and $-e_2$. We say the origin of a negative edge *-e* is the target of the positive edge $+e$ and vice versa. The meaning of this sign is similar to the `Orientation`-attribute of an `Ifc-OrientedEdge`: An `Orientation` value of `true` corresponds to the plus sign $+1$ and `false` to the minus sign -1. In our case, however, these signs are relative to the bounded face and therefore *not* a property of the edge itself but rather a property of the edge-face association.We accordingly get the following additional records for face 1:

CELL		BD				
id	dim	a	dimA	b	dimB	alpha
...				...		
1	2	1	2	1	1	+1
		1	2	4	1	+1
		1	2	6	1	−1
		1	2	2	1	−1

Note that these boundary entries are sometimes called *half edges*.

In total we get six more entries in the cells table—one for each face—and twenty-four additional entries in the boundary table. The reader can verify that, if the boundary table is considered a sparse cells×cells-matrix where the rows are indexed by `(a,dimA)`-pairs, the column index is `(b,dimB)` and the entries are the associated `alpha` values, then it returns a sparse zero matrix if multiplied by itself.

When the 2-skeleton is finished, we still do not have a valid volume model. Firstly, the volume itself is still missing; we only have an empty shell so far. Secondly, the faces do not have a consistent orientation, some are oriented counter-clockwise when seen from the inside

CELL		BD				
id	dim	a	dimA	b	dimB	alpha
...		1	3	1 ...	2	−1
1	3	1	3	2	2	−1
		1	3	3	2	−1
		1	3	4	2	+1
		1	3	5	2	+1
		1	3	6	2	+1

to the outside and others then hace clockwise orientation. Now we want each face seen from "outside" the cube to have a counter-clockwise orientation. We will say a face *points to* a side if, seen from this side, its boundary has a counter-clockwise orientation. Assuming the faces' orientations have been chosen in such a way that the horizontal faces point upwards, the frontal faces point to the rear and the sagittal faces to the right, then some faces have to be turned over (flipped). This flipping is also relative to the volume object so we obtain an entry (1,3) in the cells table, meaning that we have cell number 1 of dimension 3 and six more entries in the boundary table, thus completing the relational complex.

A boundary relation must always satisfy the fundamental property of homological algebra that, as a matrix, the product with itself must give a zero matrix, hence the boundary of the boundary is zero, which algebraically expresses the spatial property that each cell is circumscribed by its boundary. Each edge is referenced twice by a volume: once in its original orientation and once flipped to face in the opposite direction, so the sum of the products of the `alpha` entries has to be zero. The same is true for a vertex, which has an incoming edge and an outgoing edge with respect to a face.

This approach has many interesting properties:

– The data model is very easy and based on the relational model.
– Each "topological primitive" is of one common data type `CELL` and the dimension of such a cell is only indicated by an attribute.
– The data model can hence be used for spatial instances of arbitrary dimension.
– The key values of the boundary relation define *the* topology for the primitives.
– Common cells can always be reused.
– Every b-rep volume model can be represented as a relational complex.
– The asymptotical storage complexity is not worse than other geometric modeling approaches.

One property might be considered a drawback. As this model is based on homology, it cannot store a specific sequence in which edges encircle a face as some volume models do. Translating a volume model from `IfcTopologyResource` into a relational complex "abelianizes" every `IfcEdgeLoop` element (Hatcher 2002, p.99), hence every permutation of edges from such a loop is considered equal to the original sequence. Such a loss of information, however, is only of theoretical interest and we (still) see no practical relevance in it.

3.4 *Relational operators*

Basing this model on the relational model offers an interesting perspective: If one takes a relational view of topological spaces, one might, conversely, ask how relational operators can be given a topological meaning. Indeed, except for the outer join, every operator in relational algebra has a counterpart in point set topology or such topological version of an operator in question can be easily constructed.

The following table gives some example relational operators and their counterparts in point set topology.

relational algebra	point set topology
selection	subspace
rename	homeomorphism
Cartesian product	product space
inner equi join	fiber product
disjoint union	topological sum

We will later present a topological version of the Cartesian product of two complexes, hence a counterpart of Cartesian product in *algebraic* topology.

3.5 *Some geometric properties*

In topology, the geometry of cells and cw-complexes is ignored. So it is necessary to extend the data model by geometric properties in order to make it suitable for geometric modeling.

If we first consider solely planar objects with straight edges and plane surfaces, then it is sufficient to store the location of the vertices in the `COORD` table because all other cells' geometries are then defined by linear interpolation. This assumption is too restrictive for practical purposes, but the appropriate extension of the model presented here can be discussed independently. We will now describe some basic geometric properties. In (Breunig et al. 1994) a similar approach was presented for simplicial complexes.

Measures. Length, surface area, volume and maybe even their higher dimensional analogous are important properties which must be derived from the given model. The surface of a planar polygonal surface f can be computed by first triangulating the polygon and then summing up the surfaces of each such triangle.

This triangulation, however, need not cover the surface exactly. It is also possible to fix an arbitrary point p in the supporting hyperplane and then for each edge (a,b) in the polygon's boundary compute the cross product

$\overrightarrow{pa} \times \overrightarrow{pb}$.

The sum of all such cross products is a vector, where its direction gives the face's orientation and its length is twice the area of the face if all edges (a,b) are aligned with the orientation of the face itself. The reference point p may even lie anywhere so the area of a face f is simply

$$\text{area}(f) = \left\| \sum_{(a,b) \in d(f)} \vec{a} \times \vec{b} \right\| \tag{2}$$

where $d(f)$ is the set of all edges in the boundary of f. This formula, however, does not take into account that the orientations of the edges are arbitrary. But then we can use the signs from our boundary relation and hence the sum in the above formula can be replaced by:

$$\sum_{(f,e,\beta) \in \text{BD}} \sum_{\{(e,a,-1),(e,b,+1)\} \subseteq \text{BD}} \beta \cdot \frac{\vec{a} \times \vec{b}}{2}. \tag{3}$$

The cross product $a \times b$ is first computed for the boundary points a, b of each edge e bounding f. This is then mutliplied by β, the flipping of the orientation of e relative to face f.

A similar approach enables us to compute the volume of a 3-cell in our complex. We triangulate the surface (boundary) of the volume object and compute the volume of each cone (pyramid) atop such a triangle with an appropriate sign indicating whether the cone's volume is attached to the outside or the inside of the triangle. A natural choice for the cone's apex is the origin in $\mathbb{R}^3$.

$$\text{vol}(v) = \left| \sum_{(a,b,c) \in \text{surface}(v)} \frac{1}{3} \cdot \begin{vmatrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \end{vmatrix} \right| \tag{4}$$

where surface(v) is a triangulation of v's boundary such that all triangles (a,b,c) have the same orientation when viewed from the outside. Note that there is a close relationship between the cross product used to compute the area and the determinant used here to compute the volume.

The triangulation of a face, say f_1 from our example, can simply be done by fixing one boundary point p of f_1 and then for each boundary edge e of f_1 using the triangle (p,a,b), where e runs from a to b. If p happens to be equal to a or b the triangle's volume is zero, and it can be left to the discretion of the implementor and his complexity considerations whether such volume is computed and added or whether it is discarded in advance. Hence for each face f we choose one arbitrary vertex v_f and compute the triangles surface(v) as:

$$\begin{aligned} \{ (a,b,v) \quad | \quad & \text{BD}(v,f,\alpha_{vf}), \text{BD}(f,e,\alpha_{fe}), \\ & \text{BD}(e,a,-\alpha_{vf} \cdot \alpha_{fe}), \\ & \text{BD}(e,b,+\alpha_{vf} \cdot \alpha_{fe}) \; \} \end{aligned}$$

Note that most of the predicate in the above set builder expression is an inner equi join of copies of `BD`, hence 'surface' can also be generated by an SQL query. The arbitrarily chosen v_f can be the one with the minimal identifier so it can be chosen by the `min`-operator with a '`group by`' clause. The flipping of orientation is recognized by simply multiplying the corresponding `alpha`-value.

3.6 *Application: From sketch to working drawing*

We have now presented a concept for storing an arbitrary cell complex. A building, however, is commonly conceived as a union of building elements like doors, walls or columns which can be treated as if they were cells. A door, for example, somehow resembles a 2-cell combining two volumes if we disregard its relatively shallow thickness. The relational model presented above has the advantage that it is not restricted to cells and can store arbitrary complexes. It clearly makes sense to store building elements and the spatial relationships among them as spatial entities and not the cells they are made of because, firstly, this represents the semantics of a building and, secondly, many such elements have repeated patterns, and the explicit storage of the cell decomposition of, say, a frequently used joint would lead to redundancies.

To avoid such redundancies a topological version of relational decomposition and inner equi joins is needed and might also set up what can be called a "topological design theory". Such topological inner joins are well known and are called fiber products. They will be illustrated here. This replaces cells by composite objects which resemble architectural elements in a natural way.

A Simple Example. Figure 5 gives an introductory example. On the left-hand side of the figure there is a two-dimensional complex representing a (simple) floor plan. On the right-hand side we have another two-dimensional complex, which resembles this floor plan in a less detailed view where each wall and wall joint has collapsed to a cell. We will call the left-hand side complex a *working drawing* and the right-hand side complex a *sketch* to make the intention clear. So there is an obvious continuous mapping from the working drawing onto the sketch.

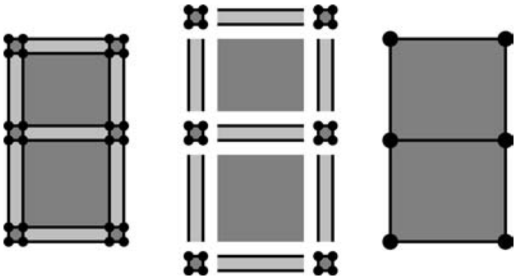

Figure 5. Two complexes representing a simplified floor plan and the fibers of the obvious mapping between these complexes drawn in the middle.

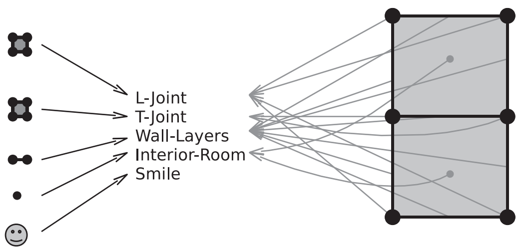

Figure 6. The floor plan sketch, the collection of details and the two mappings involved: "belongsTo" from left to middle and "uses" from right to middle.

The illustration between working drawing and sketch shows the parts of the working drawing which have collapsed to one common cell by this mapping, its so-called fibers. One observes that, in this example, each such fiber representing a wall is essentially the extrusion of the wall's profile along the cell that represents the wall in the sketch. Such extrusion is a special case of product space and, in fact, each fiber in the working drawing is essentially the Cartesian product of a cell in the sketch with some cw-complex, and this complex repeatedly occurs as a factor. We accordingly have a set of product spaces (a generalization of extrusion) where one factor is some subset from the sketch and the other factor is a complex, which we may call the *detail* or the *profile* of the sketch element.

Formalization of the Example. Each detail can now be considered a subcomplex of a collection of details. If such subcomplex is given a unique name, then this designation is a mapping from the cells of the collection of details to the set of identifiers where each detail is a fiber of this mapping which we might call "belongsTo".

We can now assign a detail to a sketch element by assigning each cell such a detail identifier, thus producing another mapping, say "uses", from the sketch to the set of detail identifiers. Figure 6 shows these two mappings.

If we now take a detail identifier then, on the one hand, there is the set of cells in the details collection which belong to the identifier and, on the other hand, the set of cells in the sketch which use this detail, so we have two fibers.

Our working drawing consists of the union of products of such pairs of fibers or, in short, the fiber product of the two mappings "belongsTo" and "uses". If a cell d belongs to a detail i which is also used by a cell s from the sketch, then the pair (d,s) belongs to the fiber product. Then the obvious mapping from the working drawing to the sketch is simply the projection of the pair (d,s) to the second component s.

Now we need a topology for the cells of the working drawing. We will proceed to show how the boundary matrix of the Cartesian product of two relational complexes detail (D,M) and sketch (S,N) can be computed, according to the EILENBERG-ZILBER-theorem (Eilenberg and Zilber 1953).

First, of course, the dimension of a pair (d,s) in our Cartesian product is simply the sum of the dimensions of both components, hence

$$\dim(d,s) = \dim(d) + \dim(s) \tag{5}$$

To obtain the boundary of a cell, we take the partial boundary matrix M for the complex which consists of the details and a partial boundary matrix N for our sketch. Then we define the partial product matrix $P = M \otimes N$: First set

$$\sigma(d) = (-1)^{\dim(d)} \tag{6}$$

to get a negative sign iff the dimension of a cell is odd and then set

$$P_{(d,s),(e,t)} := \begin{cases} \text{undefined} & : \quad (d,s) = (e,t) \\ M_{d,e} & : \quad s = t \\ \sigma(d) M_{s,t} & : \quad d = e \\ \text{undefined} & : \quad \text{otherwise} \end{cases} \tag{7}$$

The reader may verify that the matrix product $P \cdot P$ then returns a partial zero matrix.

Then our relational product complex is

$$(D,\ M) \times (S,\ N) := (D \times S,\ M \otimes N), \tag{8}$$

A generalisation of the extrusion of an m-dimensional profile (D,M) along an n-dimensional axis (S,N) to obtain the $n+m$-dimensional product complex as the "extruded object".

If (D,M) is the collection of all details for building elements instead of just one detail and (S,N) the entire sketch of the building, then the resulting product space gives a huge, complicated space where each detail is applied to each building element, where most of them do not make sense. However, it contains the products of fibers we are interested in as subspaces. It consists of all pairs (s,d) where the detail identifiers of s and d are the same.

This produces an inner equi join

$$D[\text{Join}]S \subseteq D \times S \tag{9}$$

and so we can also restrict the huge product matrix $M \otimes N$ by removing all the rows and all the columns from $M \otimes N$ which are not in $D[\text{Join}]S$ and end up with the much smaller matrix $M \otimes N|_{D[\text{Join}]S}$. We accordingly obtain the pair

$$(D[\text{Join}]S, M \otimes N|_{D[\text{Join}]S}) \tag{10}$$

which may or may not be a relational complex of our desired working drawing. Hence, additional consistency rules need to be defined to guarantee that this, indeed, is the desired result.

First, the resulting working drawing should also be a complex which amounts to testing whether $D[\text{Join}]S$ is closed in $D \times S$.

Second, as we have an inner join, we must take care that no building element gets lost in the result. Therefore the mapping "belongsTo" must map detail cells *onto* the identifiers (i.e. be surjective) and each sketch element must use such a detail. It is *not* possible to simply use a right outer join instead (Paul 2008).

Third, the connectivity information within the sketch may get lost in the working drawing. We suppose that it is possible to define a topology on the details telling us if and how they can be connected to each other. The use of these details must then be consistent with this connectivity information. The assignment of identifiers, i.e. the map "belongsTo", carries this topology over to the identifiers set such that "belongsTo" becomes continuous. This "image" of a topology is also called a *final topology*. The desired consistency in the use of details is then nothing else than continuity of the mapping "uses". This continuity of the mappings involved is also the formal prerequisite that a union of products of fibers may be called fiber product.

Fourth, the projection from our working drawing back to the sketch must be isomorphic to the original sketch. An important consistency rule to assure this is topological monotony of the mapping "belongsTo", i.e. each connected set of detail identifiers must have a connected pre-image.

Building Models as Assemblies of Cell Complexes. The above concept separates a building model into three parts: a sketch of building elements, a specification of possible details for these sketch elements and a specification determine which of the possible details is chosen for each element. To obtain a valid building model, additional topological consistency rules for the references between these elements must be observed. This separation is done in a similar way to the decomposition in relational database design.

4 COMPARISON & CONCLUSIONS

By "geometrical model" we refer to the traditional approach of developing product models by means of combining isolated geometric objects. For building models of this type, topological relationships can be computed using the algorithms presented in Section 2. In the topological approach these spatial relationships and the geometric objects can be integrated into one entity, a complex. This integration can be done at several levels of detail which are connected by continuous mappings.

The topological model is intended as a formal front-end for spatial data modeling and, similar to the relational model, it is based on a mathematical theory. Apart from this formality we see the following advantages:

- A relational complex is an extremely simple data model and so it promises that many different programming tasks which involve spatial navigation and analysis can be accomplished in a similar manner. It is a well-known fact that the simplicity of the relational model is an important factor towards improved quality of databases (Abiteboul et al. 1995).
- The spatial structure and other semantic properties are kept strictly apart and many semantics can be dynamically modeled, keeping the static data model simple. An application can navigate across a joining edge whithout knowing if this joint is an `IfcConnectionGeometry` path between two walls or a door frame and, if it needs to know, can look it up in some standardized extension of the buildings parts library used.

An overall advantage may lie in its formal foundations: It is strictly based on the underlying mathematical theory. So every engineering question which might be of a topological nature can, in principle, be found by analysing this model; every adequate topologist's tool can be applied to the modeled object and every other (finite) topological data model can be translated from and to a relational complex with all its topological properties unchanged. Indeed, the initial motivation to define this model was the wish to have a common reference model—a formal basis with which all other spatial modeling approaches can be compared.

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A comparative analysis of the performance of different (BIM/IFC) exchange formats

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ABSTRACT: This paper reports on research work done to reduce the complexity and improve the performance of obtaining IFC early binding runtime objects from stored persistent models. Various types of possible serialization and de-serialization of IFC objects were examined. An IFC ISO 10303 STEP-21, IFC XML 2X3 parsers and interpreters in addition to a STEP-P21 writer were developed by the author to be able to conduct the analysis in this paper. Comparative results and developed techniques to reach better performance are described. In order to inform the reader about the larger context of this research work and the underlying motivation, the paper presents the main interoperability aims and the rationale behind the work.

1 INTRODUCTION

A lot of efforts in the past decade have been directed towards using a central repository or a model server that acts as a base for interoperability between various AEC-FM disciplines and their software applications. In the meantime, collaborative parallel working and change management necessitate the use of Object Versioning to enable the management of a central data repository that supports long term transactions.

Thus, this research work is done as a part of the ongoing research work within the scope of the "InPro" project financed through the 6th EU Framework Program for Research and Development (www.inpro-project.eu). The research project addresses the problem of early design management and collaborative work, where the IFC model (ISO/PAS 16739, 2005) is used by a common model server for supporting the exchange of BIM (Building Information Model) related data.

The main efforts are directed towards abandoning the proprietary file based data exchange between stakeholders as shown in figure (1) to the more interoperable approach in figure (2). Meanwhile, in the BIM based approach as shown in figure (2), at the client sides, where the main stakeholders (e.g. Architects, project planners, cost estimators, HVAC, etc.) are situated, each stakeholder is allowed to optionally use a private workbench. This workbench acts as a local domain and as a sandbox, where team members inside the same organization can exchange their own local private domain data among themselves. At certain development stages of the design, a release version can be uploaded to the central project's server in a

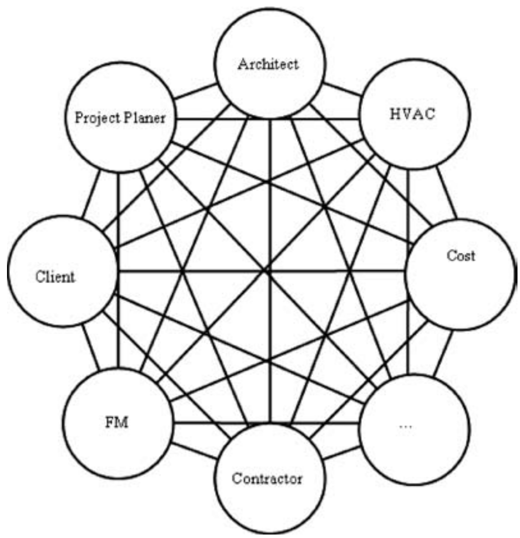


Figure 1. The current proprietary file based exchange of data in the AEC-FM industry.

"Commit" transaction to be communicated to other domains. The use of the private workbench enables the stakeholders to keep their unshared information and local versions of the design within the boundaries of their organizations and enables them to use any type of software or developing platform. The main idea behind the workbench concept is to be able to exchange shared data with the central data repository (model server) within an object versioning environment, where there

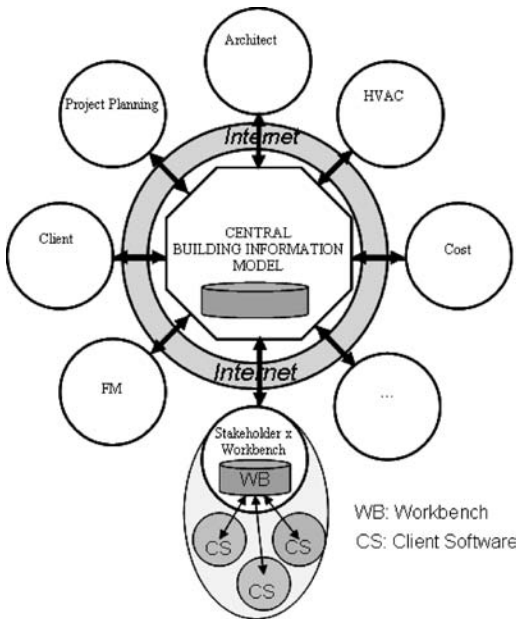


Figure 2. The main architecture of the solution approach.

is a need to manage different design versions that are produced during the design development process.

Before describing any of the solution approaches to the problem, it is worth mentioning that the main objectives of the solution approach are:

- To enable conduction of queries on the IFC model data.
- To be able to shift and navigate between object versions in relation to various (project) model versions.
- To be able to create valid partial IFC/STEP models as a result of conducting queries in the local workbench's database.

Figure (2) shows the main architecture of the suggested solution approach. A main model server acts as a data hub in the middle, where all stakeholders can exchange information through it. This necessitates that the model server should be able to exchange data with all AEC-FM domains that integrate with it through a plug and play scenario. Thus, there is a need to follow certain protocols for the data exchange, especially when considering versioning management.

It is difficult to force all software vendors to adhere to a certain exchange protocol. Hence, the workbench approach would offer a good opportunity in organizing the relation between the various stakeholders and their software tools on one side and the central model server on the other side. In addition, it helps to regulate internal workflows, approvals and data privacy issues.

The following sections describe the efforts done to establish a client (stakeholder) workbench that should be capable of both communicating with the central model server and serving the local collaboration needs and data privacy for each stakeholder's organization.

2 STATEMENT OF PROBLEM

Several solution approaches where investigated to satisfy the objectives mentioned in the introduction section of this paper. The main two approaches that achieved results are discussed within this paper. They are the mapping of the entire IFC model to a relational database at the client's (Stakeholder) side and the second is the filtering of the imported IFC model data against domain criteria to create "Domain Objects" or "Business Object".

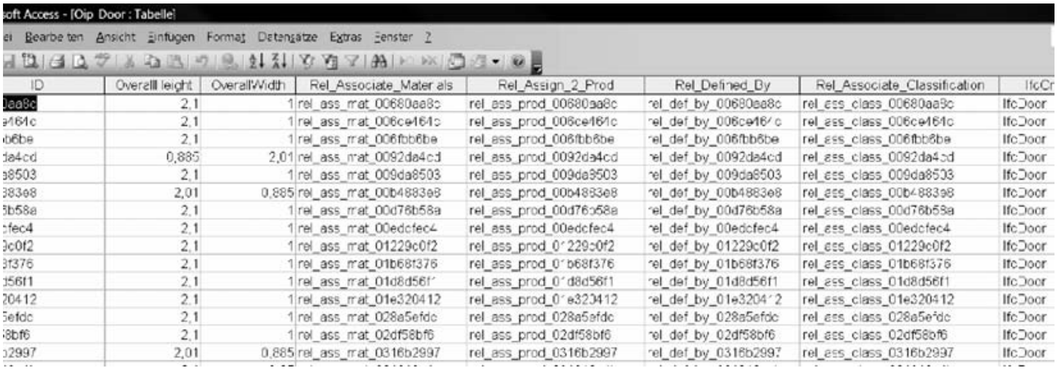
The first problem that faced the research work was dealing with the IFC/STEP (ISO 10303-21, 1994) exchange format and its EXPRESS (ISO 10303-11, 1994) definitions. The EXPRESS definition of the IFC2X-3 model had to be bound to a programming language. This was done by creating an early binging library of classes to the Java programming language. This was achieved by using the Java Compiler Compiler technology (JavaCC, 2005) for creating an AST (Abstract Syntax Tree) of the EXPRESS-Schema and then generating the corresponding Java classes by traversing the Tree.

The second step was to parse an IFC STEP-P21 file and to interpret it to the corresponding instances from the Java early binding library.

This was also achieved using the Java Compiler Compiler technology and the Java reflection package (McClusky, 1998).

The third step was to create a connection with a relational database – MS Access – (Microsoft, 2007) using the JDBC ODBC interface and to map the IFC entities to it as shown in figures (3, 4).

The IfcRelationships were mapped to the database as cross reference tables. New identifiers were created for managing the EXPRESS-P11 aggregates (List, Set, Bag, Array) and IFC elements that do not descend from the abstract entity IfcRoot as shown in figure (4). As soon as the first few trials took place several problems were discovered; among theses problems were the management of (GUIDs) Global Unique Identifiers in the Object Versioning Processes, especially with regards to GUIDs of the IFC Relationships which are not preserved within the majority of main stream applications. However, the most outstanding problem was a deficiency in performance of the database, especially with models that are greater than 2 MB. It took a lot of time to carryout a simple query that would go beyond the patience of the user.



soft Access - [Oip Door : Tabelle]

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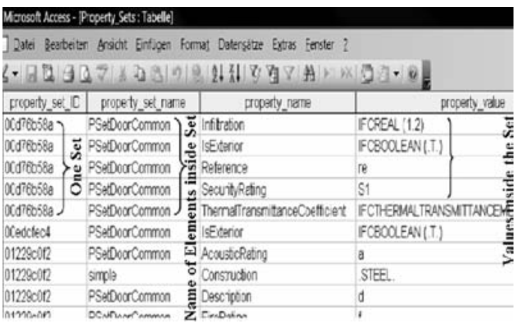
ID	OverallHeight	OverallWidth	Rel_Associate_Materials	Rel_Assign_2_Prod	Rel_Defined_By	Rel_Associate_Classification	IfcCr
0aa8c	2,1	1	rel_ass_mat_00680aa8c	rel_ass_prod_00680aa8c	rel_def_by_00680aa8c	rel_ass_class_00680aa8c	IfcDoor
e161c	2,1	1	rel_ass_mat_006ce161c	rel_ass_prod_006ce161c	rel_def_by_006ce161c	rel_ass_class_006ce161c	IfcDoor
b6be	2,1	1	rel_ass_mat_006fbb6be	rel_ass_prod_006fbb6be	rel_def_by_006fbb6be	rel_ass_class_006fbb6be	IfcDoor
da4cd	0,885	2,01	rel_ass_mat_0092da4cd	rel_ass_prod_0092da4cd	rel_def_by_0092da4cd	rel_ass_class_0092da4cd	IfcDoor
a8503	2,1	1	rel_ass_mat_009da8503	rel_ass_prod_009da8503	rel_def_by_009da8503	rel_ass_class_009da8503	IfcDoor
383e8	2,01	0,885	rel_ass_mat_00b4883e8	rel_ass_prod_00b4883e8	rel_def_by_00b4883e8	rel_ass_class_00b4883e8	IfcDoor
5b58a	2,1	1	rel_ass_mat_00d76b58a	rel_ass_prod_00d76b58a	rel_def_by_00d76b58a	rel_ass_class_00d76b58a	IfcDoor
fec4	2,1	1	rel_ass_mat_00edcfec4	rel_ass_prod_00edcfec4	rel_def_by_00edcfec4	rel_ass_class_00edcfec4	IfcDoor
9c0f2	2,1	1	rel_ass_mat_01229c0f2	rel_ass_prod_01229c0f2	rel_def_by_01229c0f2	rel_ass_class_01229c0f2	IfcDoor
3f376	2,1	1	rel_ass_mat_01b68f376	rel_ass_prod_01b68f376	rel_def_by_01b68f376	rel_ass_class_01b68f376	IfcDoor
56f1	2,1	1	rel_ass_mat_01d8d56f1	rel_ass_prod_01d8d56f1	rel_def_by_01d8d56f1	rel_ass_class_01d8d56f1	IfcDoor
20412	2,1	1	rel_ass_mat_01e320412	rel_ass_prod_01e320412	rel_def_by_01e320412	rel_ass_class_01e320412	IfcDoor
5efdc	2,1	1	rel_ass_mat_028a5efdc	rel_ass_prod_028a5efdc	rel_def_by_028a5efdc	rel_ass_class_028a5efdc	IfcDoor
8bf6	2,1	1	rel_ass_mat_02df58bf6	rel_ass_prod_02df58bf6	rel_def_by_02df58bf6	rel_ass_class_02df58bf6	IfcDoor
62997	2,01	0,885	rel_ass_mat_0316b2997	rel_ass_prod_0316b2997	rel_def_by_0316b2997	rel_ass_class_0316b2997	IfcDoor

Figure 3. A snapshot of a cross reference tables that maps IFC Relationship intacnes.



Microsoft Access - [Property_Sets : Tabelle]

Datei Bearbeiten Ansicht Einfügen Format Datensätze Extras Fenster ?

property_set_ID	property_set_name	property_name	property_value
00d76b58a	PSetDoorCommon	Infiltration	IFCREAL(1.2)
00d76b58a	PSetDoorCommon	IsExterior	IFCBOOLEAN(.T.)
00d76b58a	PSetDoorCommon	Reference	re
00d76b58a	PSetDoorCommon	SecurityRating	S1
00d76b58a	PSetDoorCommon	ThermalTransmittanceCoefficient	IFCTHERMALTRANSMITTANCEM
00edcfec4	PSetDoorCommon	IsExterior	IFCBOOLEAN(.T.)
01229c0f2	PSetDoorCommon	AcousticRating	a
01229c0f2	simple	Construction	STEEL
01229c0f2	PSetDoorCommon	Description	d

Figure 4. Modelling EXPRESS aggregate types in the relational database.

Table 1. Statistical analysis of the IFC model.

IFC Element Type	Model1 7 KB 357 elements	Model 2 8 MB 589464 elements	Model 3 161 KB 13046 elements	Average
IfcRoot	11.4%	4.6%	0.3%	5.4%
IfcRelationship	5.7%	2.5%	0.14%	2.78%
IfcBuildingElement	<1%	1.7%	0.03%	0,91%
IfcDirection	7%	3.2%	0.16%	3,45%
IfcCartesianPoint	13%	32%	25%	23,3%
IfcAxis2Placement3D	7%	4.8%	0.08%	4%
IfcSIUnit	8.5%	0.001%	0.3%	2,9%

Table 1 shows the statistical results from observing the type of data that filled up the database. Three different models representing different sizes (from 7 KB to 8 MB) were mapped to the database. It was found that the IFC elements that descend from IfcRoot, which is the common super type of all IFC entities other than those defined in the IFC Resource schema are ranging from 0.3% to 11.4% with an average of 5.4% only. The average of the IfcBuildingElements is not more than 0.91%. The average of the relationships elements descending from IfcRelatioship was found to be 2.78%. The rest is data coming from the resources layer of the IFC model e.g. geometrical data about products' representations, orientation data about the location of elements within the coordinate system and data that define the context of the IFC model (e.g. units of measurement, tolerance values, true north…etc.). It was also found that the ratio between the IfcElements and the geometrical resources describing the representation of these elements is dependent on the type of geometrical representation. For example, in models 2 and 3 the Breps descriptions used a lot of IfcCartesianPoints, IfcPolylines, IfcFaces more than the swept area solids. Thus the percentages of IfcCartesianPoint in models 2 and 3 were found to reach 32% and 25% of the entire elements of the IFC model respectively.

The analysis of the statistical results in table 1 has drawn the attention to very important questions.

1 Do we really need to map all the geometrical and context information to the database (ranging 30: 60% of the IFC model, depending on the types of geometrical description)?
2 Do we really need to map all the IfcRelationships (about 3%)?
3 Do we really need to map the objectified relationship classes (IfcRelationships) into cross reference tables in the relational database; the matter that makes the structure too complex and therefore causes much difficulty in formulating SQL queries?
4 Does the database structure need to be complicated in order to accommodate the entire IFC model?

Although the above mentioned ratios can change when dealing with different sizes and complexities of IFC models, they are still an indication for the questions to be asked and answered.

The above mentioned questions were answered by the underlying business processes (Stakeholders) within the InPro project. They have shown that a relatively smaller subset of the data is sufficient to enable their processes to take place. This subset is known as the domain model subset. It contains a set of "domain objects" or "business objects" that satisfy the business needs. Business Objects represent any object related to the domain for which the developer is creating business logic. It is an abstraction that contains attributes, values and metadata related to the underlying business process. The term "business objects" or "domain objects" is generally used to distinguish between objects the developer is creating or using related to the domain and all other types of objects he may be working with (IBM, 2008).

In the meantime, irrelevant data is considered to be a heavy burden for the processes. Furthermore, the business process only needs accurate simple information that is easy to reach and that can be trusted.

The rather complex database structure that is designed to map the IFC/STEP-21 model 1:1 does not add any value for the business process needs. They need to be able to conduct simple queries that deliver the required information away from the complexity of the IFC model and its EXPRESS definition.

Moreover, the business processes need to conduct the queries and communicate the results as partial IFC models with the outer world. Thus, there is a need to interpret the results of the queries to partial IFC models that can be compared and integrated with other models. Consequently, there is a need for a two way communication of the IFC model. Hence, the database has to include information that enables the creation of valid IFC partial models when needed.

The process modeling tasks within the InPro project have delivered a description of their business objects. They are flat business objects where their attributes contain data and not references to other objects or any inheritance hierarchy. These attributes were used to create a simple and flat relational database schema. This schema satisfies both the query and versioning needs for each stakeholder's domain.

The main problem is now how to manage the database efficiently in parallel with the different versions of the IFC models or partial models. There is a need to be able to get the right information from the database in the form of (GUIDs) as a Result Set (Sun, 2008) and load the relevant IFC model and create a partial model that contains the elements of the Result Set in a valid IFC STEP P-21 file. This partial model can be further communicated with other team members or with the main repository for the use by other stakeholders.

Consequently, the main focus of this paper is on how to create runtime objects as fast and as efficient as possible from the stored IFC STEP-P21 files.

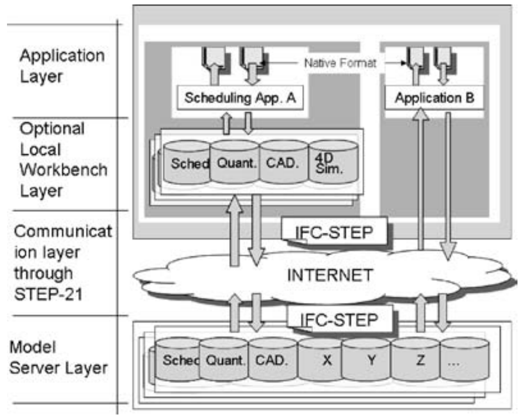


Figure 5. The overall architecture of the developed system.

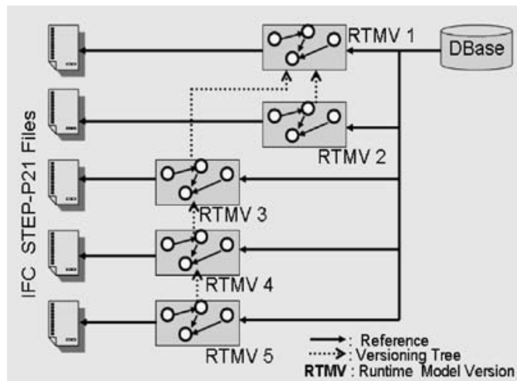


Figure 6. The communication between the versioning database and STEP-P21 files.

3 SOLUTION APPROACH

The main solution approach is described in figures (5, 6). It depends on a four layers architecture for managing the client's (Stakeholder's) workspace. It is worth mentioning that the client can optionally use the workbench or can use the direct communication with the model server depending on the type of software and its partial model exchange capabilities. Thus, there are two possible configurations for the client, either by direct communication to the model server as shown by application B in figure (5) or by the use of the workbench functionality as shown in application "A" in figure (5).

3.1 *Application layer*

At the application layer as shown in figure (5). The user is free to use any type of software that has an IFC API or where the output data can be converted to IFC (e.g. text). In cases, when processes do not include a round trip journey of data, then there is no need to have the output exported to IFC.

3.2 *Optional workbench layer*

At the workbench layer a simple and flat database structure is created and hosts the attributes of the domain objects that are necessary for the stakeholder's business processes in addition to references to any type of proprietary file formats.

The workbench enables collaborative teamwork to take place inside each stakeholder's organization. All internal workings and intermediate stages can be versioned and stored in the database. The Object Versioning Management system enables the saving of the differences (deltas) between the versions of the domain objects and thus succeeds in saving a lot of space in the database, which do impact the database performance. Moreover, the comparison between the Object Versions or different states or variants of the model in relation to the domain aspects can be easily achieved. In the meantime, any information that is not included in the database, due to not being a part of the domain objects attributes can still be obtained through the reference to the relevant version of the saved IFC STEP file. Selected information can be uploaded to the central model server at certain development stages of the work (i.e. Synchronization to model server).

If any design changes take place, the influences on the domain's processes can be easily pointed out by the database due its ability to compare the domain objects' attributes of several design versions.

The workbench can also control the communication with the central model server through several protocols that map the different model versions on the model server to their counterparts on the local workbench. Therefore, some unimplemented IFC concepts like the IfcOwnerHistory and Ownership concepts can be implemented.

Another important aspect for the majority of the stakeholders is data security and privacy. The workbench enables each organization to determine the shared and unshared data subsets of information and consequently gives the organization the possibility of hiding its own knowhow and confidential details.

The Object Versioning Management System enables the tracing of design development together with contexts of changes and hence offers a good chance for organizational learning from previous projects.

Figure (6) shows the internal structure of the local workbench layer. It consists of a relational database that depends on a flat schema representing the business objects. The main aim of the database is to enable the client to carryout queries that serve the domain needs in addition to the object versioning requirements.

Each design model version in the database has a reference to a URL where the corresponding IFC STEP ISO 10303-P21 model is stored. Whenever needed the IFC file can be parsed, interpreted and changed to a Java (RTMV) Runtime Model Version.

Each model version contains a set of objects that enable versioning at the object level. Figure 6 shows an example of a versioning tree, where design variants can be represented as a branching in the tree. Both RTMV2 and RTMV3 are variants of the same parent model RTMV1. This structure of the local workbench enables domain specific queries to take place with minimum memory needs and does not affect the database performance. If the need for any extra information that goes beyond the content of the abstracted domain model in the database arises, the corresponding IFC model version can be immediately parsed and interpreted to Java IFC early binding objects at runtime. Hence, the main challenge for this database functionality is to create a Java runtime object oriented model of the saved IFC STEP ISO 10303-P21 file to:

1 Satisfy the query needs.
2 Create valid IFC partial models that represent the Result Set obtained from the relational database.

3.3 *Communication layer*

The communication between the client's workbench and the central model server takes place over the internet in the form of STEP ISO 10303-P21 files as shown in figures (1,5). Thus, the ability to split models (create partial models), merge (update), and compare models are essential at both the workbench side and the central model server's side.

There is also a need to establish data exchange protocols between the workbench and the central model server, especially in relation to the management of model versioning.

3.4 *Model server layer*

The model server layer is expected to offer the same functionalities of the workbench, but with more capacity to handle bigger sizes of data sets and multiple domains. This should be based entirely on the IFC data structure and the underlying STEP technology. Thus, an EXPRESS based database server would be recommended as a central data hub that manages the communication between all stakeholders.

4 COMPARING DIFFERENT BIM EXCHANGE FORMATS

As stated in the previous sections one of the main challenges facing the local workbench layer (shown in figures (5,6) and the main focus of this paper is on how to create IFC early binding Java objects as fast and as efficient as possible from IFC persistent data (stored files). Therefore, various types of serialization and de-serialization of the IFC model were tested. Among these types are the IFC STEP ISO 10303-P21 relevant to the IFC2X3 schema (text), IFCxml (IAI, 2007) version 2X3 (text) and the Java Object serialization (binary format).

The main criteria for measuring the test results are the size of files and the speed of de-serialization and obtaining runtime objects.

4.1 *Testing environment*

IFC files conforming to the IFC2X3 schema version were used. All comparisons were done on a single computer (Operating System: Windows Vista, Intel Centrino Duo processor 1.7 GHz, 2GB RAM) to avoid relative differences. The virus scanner and the auto defragmentation functionalities were turned off to minimize any external influence on performance. Moreover, tests were repeated one hundred times and the average values were taken to neutralize any external influences that might be caused by other processes running on the computer at the same time or the extra overhead caused by initiating the JVM (Java Virtual Machine) at the first runs. The effect of multiple threading programming was also investigated and found to be insignificant for standalone tests.

The software used is ArchiCAD version 11 from Graphisoft. A single software package has been intentionally used to avoid relative differences of IFC output from different software sources, as it is well known that IFC files from various commercial software vendors are subject to size optimizations that can reach 66.7% reduction in size in some cases (Pazlar & Turk, 2006).

A software tool for parsing and interpreting the IFCxml 2X3 models to Java early binding classes has been written by the author based on the Java DOM (Document Object Model) technology. The tool is also capable of converting the IFCxml 2X3 model to valid IFC STEP-P21 files. The effect of conversion results in a reduction of size in comparison to the file produced from the same application that produced the XML file.

The tests show first a comparison in size between the Native ArchiCAD 11, IFC STEP-21, parsed and interpreted IFC early binding Java, parsed IFC STEP-21 (un-interpreted) and the IFCxml files of the same IFC 2X3 model.

The Java early binding of the IFC model takes place in two phases: 1) Parsing. 2) Interpretation. Therefore, a Java object model is serialized after parsing without interpretation (without binding) and is referred to as “Un-interpreted Java”. In the meantime, the same model is serialized after interpretation and is bound to pre-defined library of IFC Java classes (i.e. early binding) and is referred to as “Interpreted Java”.

Each file format was compressed using the WinZip functionality except for the object serialization for the interpreted and un-interpreted Java models. Both of them were compressed using the gZip Java functionality which is most appropriate for compressing and decompressing data at run time (on the fly) (Mahmoud, 2002). The gZip compression originally comes from the UNIX world. It compresses files but does not archive them. There is no need to archive files in the serialization of IFC Java model as it consists of one main object (IFC model). Thus, the gZip was found to be more appropriate to be implemented on a single stream of data.

4.2 *IFC testing models*

The test cases include a wide spectrum of complexity of IFC models ranging from a single wall to models of real projects’ degree of complexity.

It has also been taken into account that the structure of the IFC model could influence the results. Therefore, the test cases include cases where the geometrical description of IFC elements depends on Brep (Boundary Representation) and other models that depend on Swept Area Solids, CSG (Construction Solid Geometry) and Boolean operations.

The size of testing files ranges from 6 KB for the simplest model to 18 MB for the most complex one.

4.2.1 *Test Case 1: A single IfcWallStandardCase*

Test case 1 is the simplest test case. It is created by the author using ArchiCAD 11. The sizes of the native ArchiCAD file, the IFC STEP-P21 file, the serialized interpreted Java Object Model, the serialized un-interpreted Java Object Model and the IFCxml model with their zipped sizes and compression ratios are shown in table (2) and compared in figure (7).

It is clear that the native ArchiCAD file in this case is 70 times greater than the IFC file. This might be attributed to the reason that the file contains a lot of overhead information that is related to ArchiCAD software and not the IFC model. We will notice in the next text cases that the size of the native format gets smaller than the IFC STEP format as the underlying models grow bigger.

It can also be noticed that the IFCxml format of the model is 4 times bigger than the IFC STEP file with the highest compression ratio (79%), while the Interpreted Java file is 1.8 times bigger and the Un-interpreted Java file is 1.5 times bigger.

By examining the speed of de-serialization and interpretation of the STEP-IFC format, the Interpreted Java serialization, the Un-Interpreted Java Serialization and IFC XML, the results were found to be according to the table (3) and figure (8).

The main outstanding result is that the de-serialization of the gZipped Interpreted Java IFC

Table 2. Test Case 1: File sizes and their compression values

Model Format	Size KB	Zipped Size KB	Compression Ratio
Native ArchCAD	425	309	27,29%
IFC 2X3	6	3	50%
Interpreted Java	11	4	63,63%
Un-interpreted Java	9	3	66,66%
IFC XML 2X3	24	5	79,16%

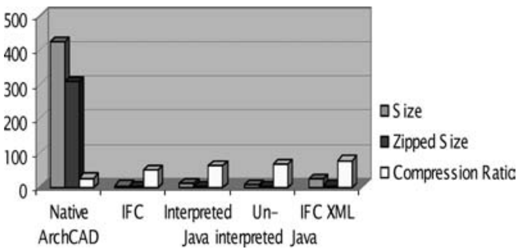


Figure 7. Test Case 1: Size comparison of different exchange formats.

Table 3. Test case 1: Files Sizes and related De-serialization speeds (figure 8)

Format	Size KB	Time Needed Seconds
Interpreted Java	11	0.3
gZipped Interpreted Java	4	0.23
IFC STEP P21	6	1.1
Un-Interpreted Java	9	1.0
IFC XML	24	1.5

model took the shortest time (0.23 seconds) to get the IFC model in the form of early binding Java classes. In the meantime, it has the smallest size (4 KBs). The savings in time against the IFC STEP-P21 model parsing and interpretation time is nearly 80%, where as the time saving in comparison with the IFCxml version of the model is nearly 85%.

4.2.2 *Test Case 2: An office building*

This test case is a rather complex model of an office building. The model is downloaded from the internet (FZK, 2008). From table (4) and figure (9), it can be concluded that, although the highest compression ration could be achieved on the IFC XML model (94%), it still remains to be the largest in compressed model sizes (0.649 MB).

From table (5) and figure (10) it could be seen that the gZipped early binding IFC Java serialization

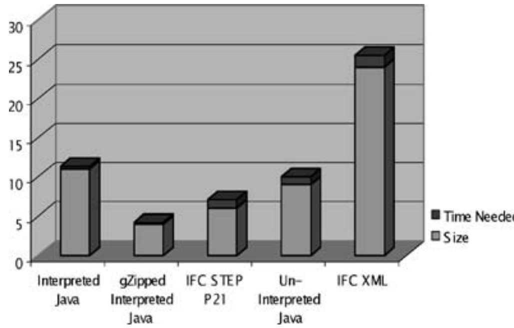


Figure 8. Test Case1: De-Serialition speeds in relation to file sizes.

Table 4. Test Case 2: File sizes in addition to compression values and ratios (figure 9)

Model Format	Size MB	Zipped Size MB	Compression Ratio
Native ArchCAD	1.34	0.636	52%
IFC 2X3	2.00	0.434	78%
Interpreted Java	3.38	0.489	85%
Un-interpreted Java	3.659	0.491	86%
IFC XML 2X3	10.87	0.649	94%

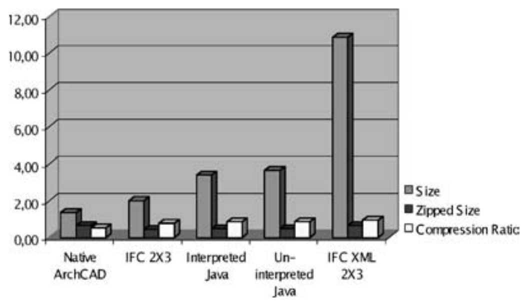


Figure 9. Test Case 2: Size comparison of different exchange formats.

has achieved both the smallest model size (after compression) and the least time needed for serialization. Moreover, it is faster than reading from an IFC STEP ISO 10303-P21 file by 62%.

4.2.3 *Test case 3: NHS office*

The test case is also a complex model of an NHS Building, figure (11). The model can be downloaded form (Graphisoft, 2008).

As it can be seen from table (6) and figure (12), the zipping of the IFC model at this size starts to achieve substantial reduction on the model size in all cases except for the ArchiCAD native format.

Table 5. Test Case 2: File Sizes and related De-serialisation speeds (figure 10).

Format	Size MB	Time Needed Seconds
Interpreted Java	3.38	4.5
gZipped Interpreted Java	0.489	2.6
IFC STEP P21	2.00	4.2
Un-Interpreted Java	3.659	6.8
IFC XML	10.87	55.6

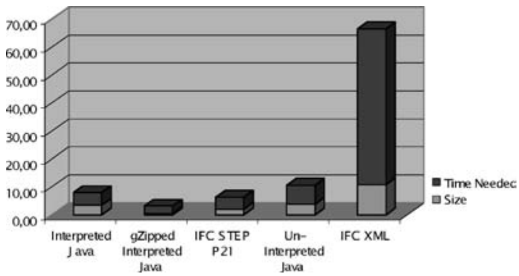


Figure 10. Test Case 2: De-serialization speeds in relation to file sizes.

Figure 11. A 3D perspective view of the NHS project.

Table 6. Test Case 3: File sizes in addition to compression values and ratios (figure 12).

Model Format	Size MB	Zipped Size MB	Compression Ratio
Native ArchCAD	26.3	23.7	9.8%
IFC 2X3	17.9	3.5	80.4%
Interpreted Java	27.6	4.0	85.5%
Un-interpreted Java	30.5	4.0	86.9%
IFC XML 2X3	86.8	4.7	94.6%

4.2.4 *Test case 4: ettenheim city*

This test case is shown through figures (14–16) as well as tables (8, 9). It is taken as an example for the relation between IFC and GIS (Geographical Information

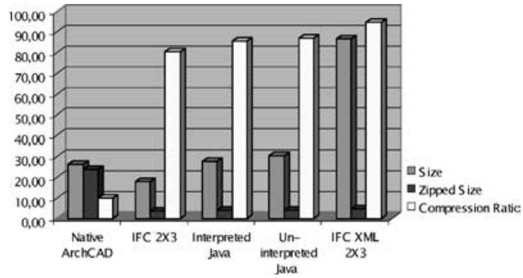


Figure 12. Test Case 3: Size comparison of different exchange formats.

Table 7. Test Case 3: File Sizes and related De-serialisation speeds (figure 13).

Format	Size MB	Time Needed Seconds
Interpreted Java	27.6	38
gZipped Interpreted Java	4.0	20
IFC STEP P21	17.9	65
Un-Interpreted Java	30.5	81.5
IFC XML	86.8	237

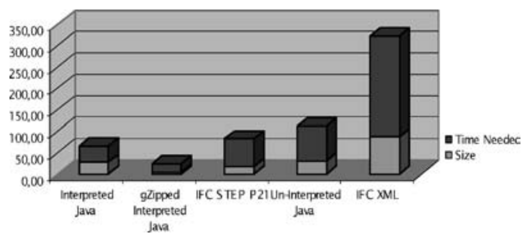


Figure 13. Test Case 3: De-serialization speeds in relation to file sizes.

System). It contains 195 buildings, 1489 walls, 380 windows and 329 roof slabs (IfcSlab Roof). It can be downloaded from (FZK, 2008).

It is quite clear that the native CAD format in this case is much smaller than the IFC/STEP format and its interpretation. Again the gZipped interpreted Java achieves a better de-serialization speed and a smaller size over the IFC/STEP-21 format.

4.3 *Test cases analysis*

Figure (17) shows a relative comparison for obtaining Java object at runtime according to the four test cases. It is quite clear that until the size of 2MB, there is no clear difference in performance. As soon as the sizes of the models grow more than 2 MB, then the differences in performance tend to be much clearer.

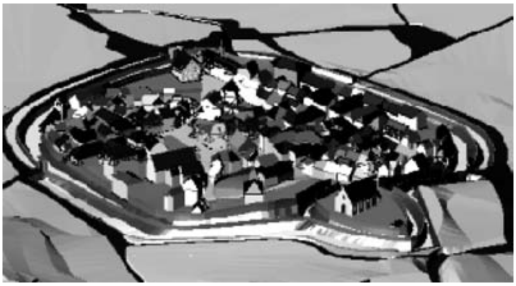


Figure 14. A perspective view of Ettenheim city.

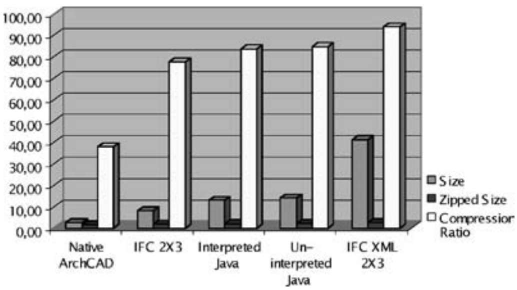


Figure 15. Test Case 4: Size comparison of different exchange formats.

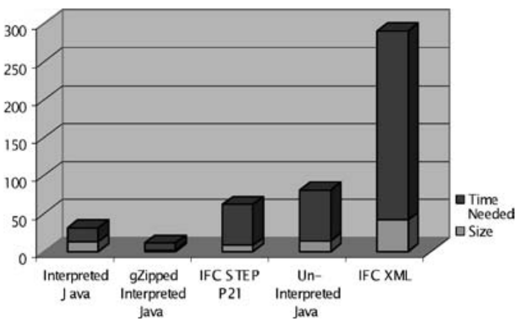


Figure 16. Test Case 4: File sizes and related De-serialization speeds.

Although the IFC XML file has the highest compression ratio (about 95%), it proves to be inconvenient for the purpose of this research work. Further more, it is usually between 4–7 times bigger than the corresponding IFC STEP-21 file. To improve the readability of figure (17), figure (18) is added, where the XML comparison is removed.

Figure (18) also shows that slopes of the curves adapt a different pattern after the size of 2MB. The best performance is achieved by the gZipped Interpreted Java object de-serialization. It showed that it can save up to nearly 83% of the time required to get hold of the IFC early binding objects at runtime in comparison

Table 8. Test Case 4: File sizes in addition to compression values and ratios (figure 15).

Model Format	Size MB	Zipped Size MB	Compression Ratio
Native ArchCAD	2.55	1.6	38%
IFC 2X3	8.04	1.8	77.6%
Interpreted Java	12.9	2.1	83.7%
Un-interpreted Java	14.1	2.1	84.7%
IFC XML 2X3	41.3	2.5	94.0%

Table 9. Test Case 4: File Sizes and related De-serialization speeds (figure 16).

Format	Size MB	Time Needed Seconds
Interpreted Java	12.9	18
gZipped Interpreted Java	2.1	9
IFC STEP P21	8.04	54
Un-Interpreted Java	14.1	67
IFC XML	41.3	249

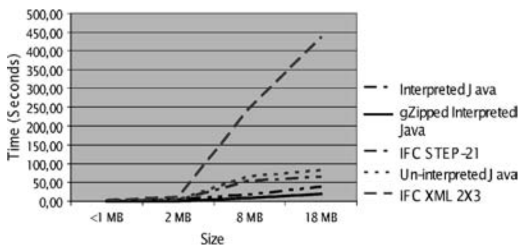


Figure 17. Comparative analysis for the test cases.

with the parsing and interpretation of the IFC STEP-21 files.

The gZipped Interpreted Java, in addition to the performance superiority has another advantage over IFC STEP-21 format. It requires in average 77% less persistent memory space. However, it could be argued that disk space is becoming no longer a problem.

The interpreted Java can save time over the uninterpreted variant because it saves the interpretation and binding phase of the IFC model at runtime.

The ArchiCAD native format was used only as an indication of the size of the model. It does not serve the purposes of this research work, as it is not possible to obtain a binding through a programming language using the native CAD format. Thus, the native format was not included in any performance measurement test. The test cases have shown that it is difficult to speculate whether the native CAD format is bigger in

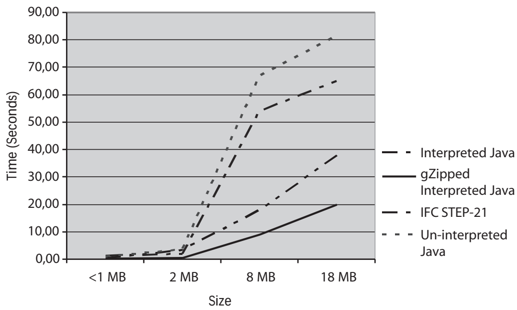


Figure 18. Relative performance for obtaining runtime objects excluding the XML format.

size than the IFC STEP-21 format or not. For IFC models smaller than 2 MB, the STEP-21 file would mostly be smaller than the native CAD format. However, as the model grows more than 2MB, the probability that the IFC model exceeds the size of the native format grows. There are also cases like test case 3, where the IFC STEP-21 is smaller. Many factors influence the size of the IFC STEP model in comparison to the native CAD format. Among these factors are: 1) The way geometry is described (e.g. using swept solids or Brep). 2) How repetition of same elements with different locations is handled. 3) Amount of semantic information (non geometry) in the model and so forth.

When writing an IFC XML parser, it was discovered that there is a very high potential for optimization of the STEP-21 files. There are often unnecessary sequences of referencing between relative locations of objects that could be optimized.

5 CONCLUSIONS AND RECOMMENDATION FOR FURTHER RESEARCH

The ability of the central database or model server that is responsible for the management of different versions of the BIM (Building Information Model) to perform queries, create partial models, integrate partial models (merging and updating) and shift between different versions of the model and its objects efficiently is considered to be an essential success factor.

In this connection, the idea of mapping the entire BIM/IFC model to a relational database has proved to impact the database's performance, especially with data models greater than 2 MB. Hence, a need was established to conduct a research work to overcome this performance problem.

The suggested solution approach is mainly build on capturing and filtering IFC/BIM domain data that is necessary for the conduction of queries and creation of needed business objects. It is envisaged that any query would result in a set of GUIDs (Global Unique Identifiers) that refer to objects within files (Model Versions) that are referenced by the database.

Various types of possible serialization and de-serialization of the IFC model were examined in terms of: 1) The file sizes, 2) The speed of serialization and de-serialization of the IFC model.

In order to be able to perform this analysis, STEP-21 , IfcXml parsers and interpreters were developed by the author together with the needed tools for mapping IFC (ISO/PAS 16739:2005) objects to the underlying relational database.

Four IFC test cases with different degrees of complexities were used to compare the performance of obtaining runtime object models using interpreted and un-interpreted early bindings of Java objects in addition to IFC XML 2X3 and the STEP-21 formats.

The gZipping effect was tested on the serialized interpreted IFC Java early binding objects and has proved superiority in both performance and persistent memory needs.

Although the work in this paper has succeeded in achieving better performance values, there is still a strong need to be able to handle partial IFC models that are manageable within reasonable size units.

The introduced solution achieves relative improvement, but does not overcome the problems and deficiencies in performance associated with large size models that can reach gigabytes.

The areas for further research are very wide. Among these areas are: 1) The interpretation of the results obtained from queries to valid partial IFC models that can be communicated with other partners, compared and integrated with other models. 2) There is a need to establish data exchange protocols between the local workbench at the client side and the central model server bearing in mind the needs of object versioning.

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Going BIM in a commercial world

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ABSTRACT: The past 20 years has seen an amazing transformation in people's perception of the world. Then, seeing really was believing. Now, we are not sure what to believe given the mix of "different" possible realities. Information sharing and communication in our working and personal lives have been revolutionised by digital technologies. Communication is completely transformed, with instant interaction between people in the remotest places across the world through computers and mobile devices. Email and internet telephony allow communication of the written and spoken word between people irrespective of where they are, as long as they have permanent virtual addresses and internet connectivity. Through the internet vast global databases can be accessed or the billions of web sites searched. Recently social networking has added a new virtual dimension to making acquaintances, perhaps replacing some of the social interaction lost through the growth of on line, at home banking and shopping. Somehow we have accepted these monumental changes in day to day living without many qualms and with great trust. The e-commerce and retail industries have grasped with enthusiasm digital ways to facilitate their business activities, attracted by the ease and immediacy of access to customers offered and the speed of electronic transactions. So, we can be reminded about insurance renewals at any hour of the day or night whilst at the same time being subtly profiled for our personal traits and preferences. This raises the question of how the digital revolution has impacted the construction industry? Have the process and procedures of building activity changed to embrace IS/IT effectively and what new opportunities are there to serve both customer and self interests? What are the barriers that beset the construction industry?

1 OBJECTIVES

This paper considers the evolution of the "model-based" concept in which the focus is on digitally representing real world constructions (comprising beams, columns and slabs) as opposed to the drawings that traditionally present information (comprising lines, symbols and text). In the 1990's the acronym CAD was applied, rather confusingly, to both Computer Aided Design and Computer Aided Draughting. To better distinguish between the two, a succession of new terms for CA Design were coined, beginning with Data Model. Nowadays the use of the term Building Information Model (BIM) is commonplace since it places emphasis on building information which may be design related but may equally be cost, time, performance or regulation related. The paper considers the degree of penetration of Building Information Models (BIM's) into industrial and commercial use and the technology, business and cultural changes needed for that. This paper draws on case studies of companies working at different stages and supply chain positions within the construction process, highlighting blockers and opportunities to progress and speculating on what the short to medium term future. It also discusses the importance of "organisational e-readiness" and assessing in measurable terms how 'ready' organisations are to adopt, invest and use available IS/IT to achieve sustainable competitive advantage with continuous improvement. The competencies that an organisation needs, prior to any BIM investment, centre on people, process and IT infrastructures.

2 PROBLEM STATUS

2.1 *Overview*

Where has the last twenty years got Us?

The global marketplace

The past twenty years has seen an amazing transformation in people's perception of the world, much of this change has been driven by the introduction of technologies which couldn't have been dreamed of. For instance, Microsoft delivered Windows 386 v2.1. Hewlett-Packard introduced the HP DeskJet ink jet printer with a price tag of US$1000, IBM launched the PS/2 Model 30 286 with 512 kB RAM and a 20 MB hard drive. In the CAD world, Autodesk shipped Auto-CAD Release 10, with 3D enhancements and Auto-Solids. CATIA Version 3 was announced with AEC functionality and became the automotive applications leader? Unigraphics announced commitment to UNIX and open system architectures and a STEP-compatible parametric solid kernel for 3-D modeling was introduced. Finally, from Intel's General Manager Richard Bader, came the honest remark: "The market is confusing, although it provides us with some sort of job security".

2.2 *The UK construction market*

So with exactly the same opportunities how has the digital revolution impacted the construction industry?

Clearly not as far as some other vertical sectors and there are some perfectly reasonable mitigations, it's a large disparate industry, it is highly fragmented and has low barriers to entry. The contractual rules of engagement have changed very little from when they were drafted at the end of the Victorian era and we have stopped developing and training our tradesmen. The margins are low and most innovation is carried out not through client pressure, as no one client is large enough to affect the market sufficiently (the opposite in fact to the automotive or aerospace market) but when the market tightens and businesses are faced with survival options.

So it is interesting to see which technologies and processes have been adopted and how they have been adopted to meet the needs of the industry. The premier killer application or technology must be the mobile phone. The universal communicator, it's small reliable and relatively cheap, it is followed into second place by email, the solution to all communication issues not covered by the phone.

There has been a gradual adoption of personal computing where our love for spreadsheets and access databases sprang up to fill the gap left when we realised that mainframe computing and leased line net-works, while adequate for the office environment, didn't fare so well in the project environment and had no place in the world of integrating a supply chain.

Then in the early 90's we discovered we could use the internet and a whole new world opened up, for roughly the right price we could communicate with anyone we wanted to anywhere and with this the first widespread construction process management tools appeared with the launch of the "Collaboration Tool" and it could be said that a well run Collaboration system provides us a common data environment or Mk 1 BIM.

The use of these tools has started us down the route of understanding the importance of process as well as data. For a long time the focus has been very data centric and while connectivity was limited this possibly wasn't an issue, but now with the data sharing possibilities available we need to be sure of the status and validity of our data sets, be they lines and vectors in our design, environmental or commercial data.

The improved organisation of processes and data is now allowing leading firms to not only take the benefits of improved productivity in this area but also to start to look at how they can reuse data to form useful information and knowledge. This highly structured view of our data is fundamental to the effective implementation of BIM and at current progress could take some organisations many years to achieve.

As we have discussed above the leading organisations are implementing processes and controls with electronic tools to automate and reduce costs. This is a major step forward from the old ways of working, which were confused in the late 1980's with the fascination of the market with Quality Assurance and the poor way it was implemented into most construction businesses. In a move away from the procedural world we developed processes. This has been a subtle change but vital in creating consistency in the industry and equally important if we want to achieve the goal of universally integrating supply chains through the use of BIM. An interesting development has been the alignment of business processes with strategic business goals and looking at measurements of this alignment and we will discuss this in detail later.

Another significant development has been the consolidation and globalisation of the market. Contractors started the trend with a number of big UK names being bought out, including Laing, Mowlem, Wimpey, AMEC D&B/Civils and more recently Alfred McAlpine. Completely unpredictable in 1988? This trend is now evident in the Consulting Engineering market, with players such as Atkins, RPS, WSP and Scott Wilson all actively acquiring over the last 18 months.

Considerable activity has also been seen in the technology market, accelerated in the last decade with the widespread availability of the Internet at more reasonable prices and the wider possibilities of sharing project data, through email and collaboration systems. This has led to improvements in the understanding of standards and the introduction of process management as well as data management in the latest BS1192:2007 covering the creation and management of construction data.

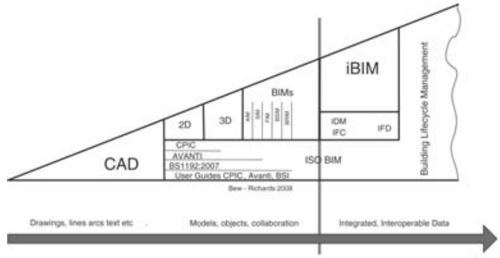
A key issue all businesses seem to share is maintaining a persistence of knowledge within the organisation as employees come and go. A global market place for our clients also presents a global market place for our people and the constant churn moves experience and knowledge around, while data remains resident in file systems and archives, rather than being focused to deliver a better product to our clients.

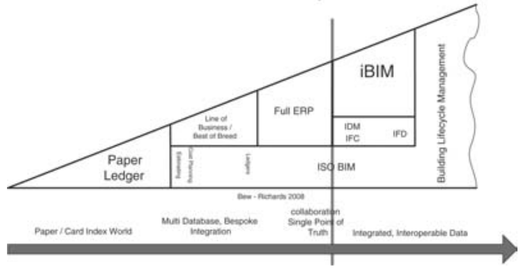
This is detailed later in our review of the people issues, looking at the industry's ability to improve and sustain organisational learning on a commercial basis. This point leads us to the maturity of our industries overall e-readiness and ability to deliver a sustainable quality service.

The final issue to be addressed is the technology adoption as a whole and how each generation of technology has enabled an advance in performance but when combined with the other two influencers fails to deliver to our expectations. The models below are designed to plot the progress of both the engineering and commercial worlds and to offer a view as to where businesses are on the evolutionally journey and the issues which need to be addressed to get to full iBIM adoption.

Both the commercial and engineering streams have progressed in a parallel fashion taking the initial steps gaining confidence and acceptance in the move from manual ledgers or drawing boards and then in some ways not moving significantly in terms of the ways and methods they have been adopted but in many cases improving immeasurably in terms of functionality and reliability. It is often cited that only around 15% of MS Word functionality is used by most users of the product and similar is true of many of our engineering and commercial tools. The uptake has improved with the more widespread use of internet web based tools for the sharing and collaboration of supply chain information. It is this step that has in the main driven the need to improve not only the standardisation of data management but also the heightened awareness of the need to standardise processes as it is only once these two issues are managed that effective supply chain information exchange can take place.

Technical improvements have continued and the emergence of object based technologies, the ability of systems to treat data in a way that we recognise in the real world including the effective implementation of 3D technologies has seen the development move on to the point where we have 3D graphical models with the capability of identifying lines and arcs with real world "items or objects" with which we can attach data, that





can be inherited and abstracted in a manner similar to that in which we interpret and interface with the real world. Unlike in our mind these models have been delivered in the main as single disciplinary renditions with little capability of being integrated or exchanged either from a data or process standardisation point of view. While this can be managed from a data point of view by remaining in a single proprietary arena, when faced with a large and disparate supply chain this has presented us with some significant challenges.

A similar story can be articulated in the commercial world with paper systems being replaced either by monolithic mainframe systems, or over simple accounting ledgers, they in turn being replaced by line of business systems glued into so called best of breed systems with all the bespoke integration and support costs they incurred. The large ERP vendors moved into the sector in around 2001, and now have various levels of installations in most of the larger businesses.

Each of these scenarios when plotted on the evolutionary ramps indicated above place most businesses somewhere to the left of the red line. To move past this point we need to enable an object based process and data exchange environment in just the same way that Collaboration and BS 1192:2007 have enabled in the more current traditional file based world. This vision has been well articulated by the International Alliance for Interoperability (now working as Building Smart) and has led to the definition of the Industry Foundation Classes (IFC) and various process definitions. To date these have been defined and taken to the market in the form of case studies and pilots in various parts of the world and we now face the challenge of applying these techniques to the vaguearies of our own UK market which forms the basis of the remainder of this paper.

2.3 *People and organisational e-Readiness*

The past decade has witnessed significant investments in IT. The global investment in 1996 was estimated at $11 trillion of which $250 billion was spent in the US alone (Brynjolfsson & Hitt 1998 and Strassmann 1997), compared to $35 billion in the UK (Willcocks and Lester 1996). However, a study conducted by the Standish Group (1999), incorporating data from several thousand IS/IT projects, revealed that only 26% of those projects finished on time and within their estimated budget, while 28% were terminated before they were finished and the remaining 46% involved going over budget and over running (Cunningham 1999). Furthermore, in spite of the early studies that indicated the need for IT investment to be carefully planned and aligned with business strategies, a large percentage of systems have failed to achieve their intended strategic business objectives. A recent study carried by the University of Salford identified that 75% of IT investments did not meet their business objectives (Salah 2003). As a result, these projects were either abandoned, significantly redirected, or worst still, 'kept alive' in spite of their failure. Clegg et al. (1997) undertook an empirical study surveying approximately 1400 organisations and showed that 80–90% of IT investments did not meet their performance objectives, while the reasons for this were rarely purely technical in origin. Such statistics together with high investment have raised serious concerns regarding the successful implementation of IT projects. In addition, the disillusion in not gaining strategic benefits from IT has led to many organisations not investing in IT to achieve competitive advantage (Goulding & Alshawi 2004, Peppard & Ward 2004 and Zuhairi & Alshawi 2004). Furthermore, this has contributed to driving a gap that exists between IT and business personnel, whereby executives do not fully recognise IT in terms of its function and value to the business and IT personnel do not posses an understanding of the business (Basu & Jarnagin 2008).

Such high percentage of systems failure is rarely attributed purely technical in origin. They are more related to the organisational 'soft issues' which underpin the capability of the organisation to successfully absorb IS/IT into its work practices. IT is still, in many cases, being considered by the management of organisations as a cost cutting tool or utility (owned and managed by their IT departments). This 'Technology Push' approach alone, even though to some extent is still dominating in many industries like construction and engineering, will not harness the full business potential of IS/IT and therefore is unable to lead to sustainable competitive advantage. Although the implementation of a few advanced IT applications may bring about 'first comer' advantage to an organisation, this will not be sustainable as it can be easily copied by competitors. The only mechanism to ensure sustainable competitive advantage is the innovation in process improvement and management along with IT as an enabler (Alshawi & Faraj 2002, Alshawi & Goulding, 2004, Obaide & Alshawi 2005). This therefore requires an organisation to be in a state of readiness which will provide it with the capability to effectively absorb IS/IT enabled innovation and business improvement into its work practices (Hafez & Alsahwi 2005).

Organisational capability is the ability to initiate, absorb, develop and implement new improvement ideas in support of organisation's business objectives (Alshawi 2007). It is also referred to as the strategic applications of competencies (Kangas 1999, Moingeon et al 1998). The process of building the organisational capability is the development and deployment of specific organisational competencies.

The competencies that an organisation needs to develop in order to acquire the capability to strategically benefit from IS/IT, prior to IS/IT investment, falls under four main elements, namely people, process, work environment and IT infrastructure. These elements are highly interrelated whereby developing competencies in one element requires improvement in the others. The core competency is process improvement that an organisation has to develop in order to achieve the required IS/IT capability. However, implementing process improvements requires people with the necessary skills and power. This in turn requires the consent of the management together with the creation of an environment that can facilitate the proposed change (implementation) through such activities as motivation, empowerment and change management. A flexible and advanced IT infrastructure can enable a high level of integration between these elements (Alshawi 2007).

The first two elements are the key to change and improvement while the other two elements are enablers without which the first two elements can not be sustained. The 'acceptable' level of IS/IT that can be successfully utilised in an organisation to ensure its business benefits are realised therefore depends on assessing a range of critical issues needed to ensure a balance between the organisation's readiness (mainly factors required to adapt to the proposed change) against the level and complexity of the proposed IT (which often hinders or limit success). This balance often includes many issues such as capital expenditure, resource availability, organisation's maturity and readiness, culture and vision and available IS/IT skills (Salah & Alshawi 2005).

The time required for an organisation to build its IS/IT capability is highly dependent on the level of maturity of the organisation in each of the four elements. In terms of maturity, this is the adoption of 'good practice' in relation to a framework

Table 1. Categorisation of the current IS evaluation approaches.

Approach	Type	Details/Examples	
Product-based	System Quality	Focuses on performance characteristics such as resource utilization and efficiency, reliability, and response time	
	System Use	Reflects the frequency of IS usage by users	
	User Satisfaction	Widely used approach which is based on the level of user satisfaction	
Process-based	Goal Centred	Measures the degree of attainment in relation to specified targets. Examples: GQM (Solingen & Berghout, 1999) and ITIL (Central Computer and Telecommunications Agency, 1992)	
	Comparative	Benchmarking approach	
	Improvement	Assesses the degree of adaptation of a process to the related changes in requirements and work environment.	
	Normative	a. Maturity-based b. Non-maturity based	Measures performance compared to external standards. Example CMM, ISO standards
Organisational Maturity	General Models	Examples of such models are those by: Nolen (Nolan, 1979); Earl (Earl, 1989); Bhabuta (Bhabuta, 1988); and Gallier and Sutherland (Galliers & Sutherland, 1991.	

which encourages repeatable stable and well-defined results. It is defined by the degree of which organisational processes and activities are executed following principles of good practice. Therefore mature organisations systematically undertake activities that are applied consistently across the organisation, while the outcomes of immature organisations are improvised through individuals. The development of an organisation is normally described in a simplified way using a limited number of maturity levels through which it sequentially progresses. Each level is described by a set of criteria that characterises an organisation at that particular level. These levels of maturity do not provide guidance on how to run an organisation, but rather a way to measure how mature an organisation is based on key processes and practices. Therefore, a maturity level is an indication of the effectiveness and efficiency of the organisation (Alshawi 2007).

If an organisation is to achieve the required level of capability to address IS/IT based innovation and continuous improvement, then it has to:

- Create an innovative work environment: focused on developing and sustaining a highly skilled and flexible workforce which will have the skills and the competencies to continuously introduce improvement through better and more streamlined business processes enabled by advanced IT. In this context, organisational learning and knowledge management become a necessity for organisations to sustain business improvements and competitive advantage out of their IS/IT investments.
- Achieve effective business process and improvement: focused on improving the organisation's efficiency by directly integrating IS/IT with the corporate, strategic and operational needs. This ensures IS/IT resources are 'in line' with business imperatives.

2.4 *Measuring IS/IT success*

A wide range of measurement approaches for IS/IT success exists which can be divided into three different categorises according to the focus of the evaluation (Table 1):

- IS as a product which is concerned mainly with the technical success, user satisfaction, use, and financial impact.
- the processes which underpin the development of an IS of which the measures are developed with the aim of improving the IS development processes.
- the maturity of IS within an organisation in terms of IS planning, infrastructure, utilisation, and the management of IS functions.

However, many of the existing evaluation measures have been criticised in the literature for suffering serious shortcomings, especially in the way in which they evaluate the IS (Irani 2002, Chan 2000). Firstly, product-based measures suffer many limitations: a) a technically sound IS does not guarantee that it would be accepted or used by the user, or that it would meet its planned objectives (Ballantine et al 1996); b) the Usage Level is vulnerable to the work environment and personal circumstances; c) User Satisfaction has also been criticized in that satisfied individuals would not give rise to a successful system that meets its objectives; and d) the financial measures also suffer from limitations in capturing the actual value of IS projects within organisations. Secondly, process-based measures also suffer many limitations. For example, they are developed to assess the process which underpins the development of IS projects and not to assess the effectiveness of IS projects on business processes and business objectives. Thirdly, although the general measurement approaches explain the basic idea behind the evolution of IS in organisations, they are simplistic and may not reflect reality, especially in light of the current pace of change in technology.

Furthermore, the majority of the current IS measurement approaches are mainly post-investment measures which attempt to assist mangers in reviewing the results of their decisions on IS/IT investments and to assist them in future related investments. Hence, they do not address fully the critical elements (mentioned above) prior to the implementation of IS projects. This clearly highlights the lack of organisational related and pre-investment measurement approaches which are necessary to help organisations carefully prepare the appropriate "organisational" conditions in order for IS projects to succeed. Such approaches need to embrace the key organisational elements that can hinder the successful implementation of IS projects.

If an organisation is to develop an IS/IT capability then it needs to rethink its processes, structure, work environment and people. This necessitates a 'forward looking' management tool which will enable managers to (Figure 1) (Saleh & Alshawi 2005):

- Undertake a general assessment of the 'current capabilities' of the organisation with regard to the key organisational elements and those associated aspects that impact on the development of the required capabilities, i.e. establishing the current state of an organisation's readiness.
- Predict the 'required level' of change and resources to develop the target/required capabilities, i.e. identifying the organisation's 'readiness gap' for developing and adopting specific capabilities.

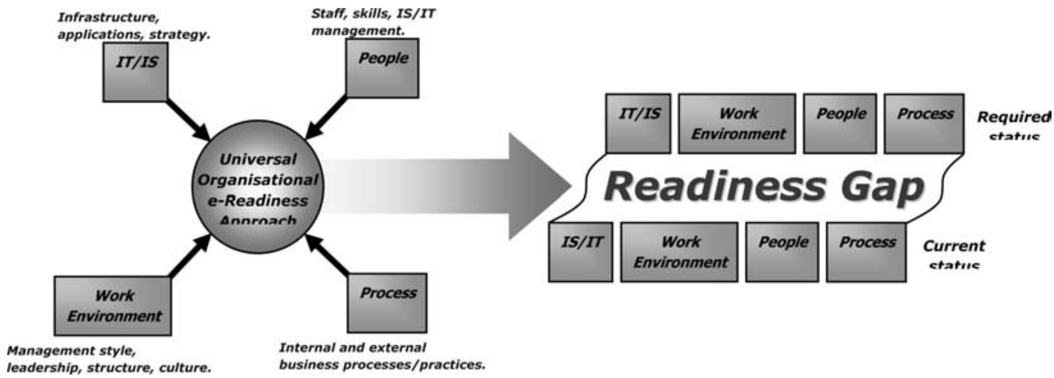
Saleh & Alshawi (2005) examined the organisational readiness of a public-sector institution, that provides services and receives public and government money which it invests, in terms of the key elements of people, process, work environment and IT infrastructure in assessing the readiness of the organisation. The project was the development of a large 'stand alone' personnel information system, based on an inverted-relational database management system, to accommodate about 800 employees. Four years from the time the project started and at a cost of between US $7 to 10 million, the project was declared a failure. Over a decade has passed from the time the first study for a new system was conducted and the organisation still has its existing 20 year-old mainframe system.

Several issues in relation to the key elements contributing to the failure of the IS/IT investment were identified. It was established that experienced (vendor) staff agreed upon by the organisation were only assigned to the project for a short time during the early stages of the project. This withdrawal of experienced staff also negatively affected the organisation's trust in the vendor. A distinct lack of positive relationships between different groups was present in the organisation, which caused resistance to needed change in structure and processes.

A lack of strong support from the top management also prevented the project team from implementing necessary changes in the processes and structure. While their decisive leadership allowed the conflicts between different entities in the organisation to escalate right up to the end of the project, which had a negative effect on the project success. As top management caved in under the pressure of both IS/IT unit and user groups, the project team was not allowed to modify the organisational structure when it was obviously needed to solve some of the design problems that appeared later in the project. Key staff considered keeping knowledge and experience to themselves as a job security tool therefore they were not forthcoming in cooperating with the project team. Such an individualistic culture almost entirely prohibited the existence of in-house training programmes for new and junior staff by senior and key staff. In addition, the project team did not make an effort to relieve the tension in the relationship that occurred with users caused by the introduction of the project. This should have been addressed through the introduction of an awareness programme to explain the benefit of the project and work towards eliminating unfounded suspicions amongst users. As the design of the new system was not successful in resolving the ownership of the data within the organisation this caused additional user resistance to the project. Further resentment of the user was caused through the vendor treating the project as a new system within an organisation that had no prior systems, i.e. the new design changed all the interfaces and environment that the user was familiar with. The understanding/perception of the user was that they were to forget their experience and knowledge that they had built over many years. However, this knowledge and experience was considered by many key users as giving them their value in the organisation. Finally, the 'strategic study' that was undertaken by the vendor did not address the real problems with the system in that many of the performance indicators were not applicable to the actual situation, i.e. they were important for the vendor's own experience in other countries' environment but not the actual indicators for the user manager. The project leader believed the vendor purposely avoided highly sensitive areas such as culture, processes and structure as their main concern at that time was to simply win the contract.

3 PROCESS

Davenport (1993) states that "a process is simply a structured, measured sets of activities designed to produce a specified output for a particular customer or market" and he continues stating that "processes



are the structure by which an organisation does what is necessary to produce value for its customers.

This holds true to this day and it is interesting to observe how processes have really only risen to the top of our agenda since we have discovered how to transact with third parties outside the corporation. In the Mainframe days this was straight forward in a proprietary world, but over the internet to our wider supply chain things must be more formal or we see breakdown and none of the benefits working in a collaborative way can bring.

The old paper processes were slow and methodical. Our data definition was simple (usually only 4 layers of tracing paper or film). We knew how long it took to complete a drawing and we could all read drawing issue sheets and everyone had a paper copy of every drawing in the rack. Digital systems have brought advances in accuracy and productivity especially in rework, but faced us with a whole raft of other management issues. In 1995 the Process Protocol project agreed with the conclusions of Latham (1994) who confirmed all the previous studies and concluded that the fragmented nature of the industry, lack of common processes and very poor adoption and use, as major factors contributing to the poor communication between all parties working on a construction project. Some of the major outcomes of this investigation are (Latham 1994):

- Although a number of changes have been identified in previous investigations of the construction industry, the majority of them have not been implemented. This shows that the construction industry might be inherently resisting to changes
- Clients are the main parties which could instigate changes in the industry and therefore they have a responsibility and a part to play in this change process and none more than the government itself
- There is a need for more effective collaboration between clients and contractors
- There is also a need for effective processes throughout the construction life cycle starting from the management of the client brief to the selection of the supply chain participants and eventual construction/on-site processes.

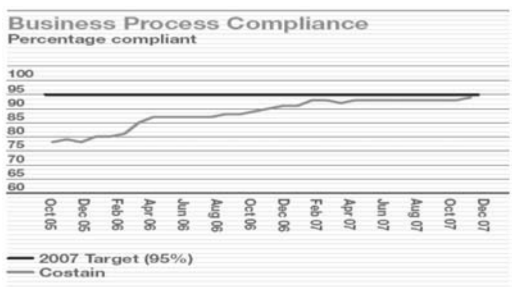
The main outcome and recommendation of the Latham report is that it calls for significant cost savings by the utilisation and formulation of effective construction processes which will in turn lead to increased performance. The recommendations of the Latham report are repeated by Sir John Egan “Rethinking Construction” (1998). This report identified five key drivers of change which need to form the agenda for the construction industry

- Committed leadership
- Focus on the customer
- Integrated processes and teams
- Quality driven agenda
- Commitment to people

Within the focus for integrated processes and teams, four key elements are identified which include: product development; project implementation; partnering the supply chain; production of components. Furthermore, the Egan (1998) report calls for a total performance improvement by 30% requiring significant improvements in the way the construction process is enacted. This still requires a significant re-engineering of construction process involved in the end to end delivery of a construction based asset, through into operations and demolition.

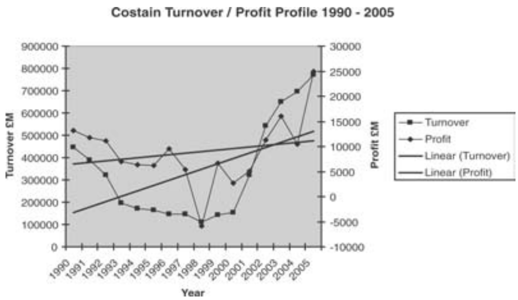
There have been other more generic approaches at the implementation of processes and some initiatives which probably did the cause a disservice such as BS5750, but its successor ISO9001 has, together with approaches such as EFQM, begun to get the whole understanding of process management and the undeniable linkage between well run business with good well implemented processes are coincident to those which enjoy good levels of commercial success. There are few documented examples of this in the UK but one such business Costain Ltd a UK based contractor embarked on a combined business, technology and process strategy and demonstrated that as their level of business process compliance improved so did their volume and profit. The following quote is taken from their 2007 Annual Report.

"Measurement and Compliance with Business Processes is measured in Costain through the Implementing Best Practice (IBP) programme, which involves each project being formally assessed at 6, 10 and 26 weeks after project commencement. These assessments check compliance with the Mandatory Gates and Controls as defined in IBP. These assessments are formally recorded and reports are issued to the appropriate Project Team and Sector/Regional Director. Each measurement is a percentage of the mandatory parts of IBP that have been complied with at the time of the assessment and therefore target compliance should always be 100%.



There is a clear correlation between the IBP Compliance at six weeks into a project and the performance of the project in terms of cost, profit and time. Integrated with the process, Costain produce reports on all health, safety and environmental issues and incidents.

Therefore the IBP Compliance provides an early indication of the probable eventual outcome of a project. Targets are established each year and progress towards that target is measured monthly and discussed at board level, with senior management tasked with providing action plans as necessary to bring about improved compliance and performance."



This approach is now being repeated in a number of organisations as the message and continued consistency in improvement is seen as a necessity for survival in such a low margin sector.

One differentiator of the Costain story was the integration of the business, process and technology strategies and with it came the implementation of two key enabling technologies; the enterprise collaboration system and Enterprise Resource Planning (ERP) System. Both of these systems can only thrive in an environment of consistent process, which clearly lead to the improvement in performance.

The structural steel market place has benefited from a lot of technological development mainly sponsored from the Process Engineering end of their market which has been available to enable the full digital integration of the production lifecycle. These capabilities have been available for over a decade and yet the level of adoption is minute.

Why?

The technology is available, but there are no consistent processes for production, sharing and most importantly checking and approving. So by default all of the data which is created has no formal status and a sub-set of the data has to be created (called a drawing) to enable the design to be checked and approved for use. This coupled with the lack of end to end understanding of the system and process implementers has led the practitioners to have such low levels of trust in the available data (for whatever reason), they prefer to trace and deduce it from the available 2D records.

The location of these checking points throughout the delivery process are various and are derived from the need to guarantee the integrity of a structure or member, the satisfaction of legislation or planning or for the recovery of fees or other payments due. We have many procurement routes defined by various forms of contract each purporting to be specific to a need or circumstance. In the main design and construct contracts of all description tend towards the JCT various forms in the UK. With its origins in the divide and rule approach of the Victorians, while very successful in achieving some form of cost certainty, protection to its client has very rarely been held up as the most collaborative and best value methodology, although moves have been afoot recently to address these issues. Some clients aware of these issues and seeking to capitalise on the benefits of getting best value as well as best cost have moved to the more collaborative models such as NEC and the various target cost methods, which draws on the attractive features of "construction management" and "management construction" to deliver a product that meets the clients requirements without the compromise of the traditional routes.

If the procurement route (contract), technical and legislation checking points were standardised, together with the structural and quality checking processes this would give a number of process "focus" points throughout the delivery process. The responsibility of the individual organisations to maintain consistency and profitability would remain their own but it would be clear as to what the supply chain needed in terms of process as well as data at each point.

This approach is now beginning to be formalised in the file base collaborative world. BS1192:2007 has for the first time a clear description of the business processes required to deliver "Construction Production Information". The BIM equivalent to this is the Information Delivery Manual (IDM) which is ongoing definition of processes to deliver the overall Building Information Model product. But to get to the point whereby an IDM can be used from a process point of view we need to have moved our way up the evolutionary "Ramp" discussed above. It took over twenty years of CAD to get a defined process and data management standard in the UK. How long will adoption of this take? How long will it take organisations to take the lead that Costain did and realise that there is a good commercial case to do this where ever you are in the supply chain, because until you find two businesses with good quality processes in place which are compliant with the interface standard (in this case BS1192:2007), progress cannot be made.

4 TECHNOLOGY

As industry moves towards the ubiquitous use of BIM, as we have discusses, there must be a realisation that this is an evolutionary process. There is no point in waiting for a complete solution to emerge before making use of what is available. For instance, we know that interoperability comes out top of the wish lists in major surveys but that doesn't mean that you should wait for perfection in IFC based interoperability before buying whichever application suits you. The situation is in fact much like Word processing was 20/25 years ago. Then there was a market leader (WordStar), simple text based file exchange (tags used for mark up were different for individual applications). Now we still have a market leader (MSWord) but we have the very rapid emergence of XML based open document formats that are international rather than proprietary standards.

When we move from the proprietary (pBIM) to interoperable BIM, we declare an interest in exposing the BIM objects that we use to other applications. Exposure here means that you make available services that can work with the objects. In an IFC based world, such a service would be an IFC query or operation. This works similarly for formats such as gbxml (Green Building XML), CIS/2 (CIMsteel Integration Standards), GML (Geographic Markup Language), CityGML, ISO 15926 (process/offshore industry) and more.

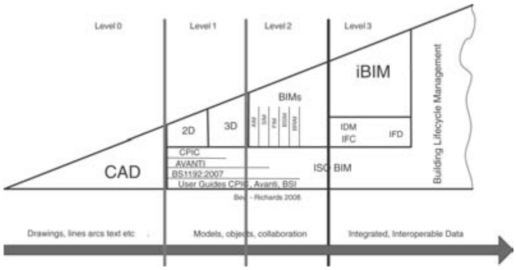
The essence of the query/operation is that it should relate to a business process. Practically, it should 'expose' the data that is required by pairs or groups of actors at that point in the lifecycle of the building construction process with a mechanism to ensure the quality of the data at the point of the transaction. This is the aim of IDM which is considered in more detail by other papers.

5 THE EVIDENCE

Our search for working case studies has helped polarise our view that the red line on the 'ramp' diagrams in the line between current best practice and our most optimistic view of where we would like to see iBIM's. The examples described below have been selected as representative of each of the various stages of evolutionary development described by the 'ramp'. Unfortunately the various methods of benefit measurement are inconsistent over the projects but we have attempted to draw some overall observations and characteristics.

BIM Evaluation as we have discussed is about a journey of building your data and process sets and improving as you progress. The benefits that can be accrued at each evolutionary step can be seen through the case studies to improve incrementally and it is anticipated that the step to stage three will yield even more significant returns.

- Unmanaged CAD usually 2D with paper as the most likely data exchange mechanism
- Managed CAD in 2 or 3D format using BS1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration.
- Managed 3D environment held in separate discipline tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware. Could be regarded as "pBIM".
- Fully open interposable process and Data integration enabled by IFC / IFD. Managed by a collaborative model server. Could be regarded as iBIM.



5.1 *BIM level "0"*

We haven't attempted to present case studies at this level of the evolution in this paper as the focus is towards the top of the evolutionary ramp. It is however worth noting the figures quoted by the research into the US market by the National Institute of Standards and Technology (NIST) in 2002. This stated that the cost of poor interoperability was estimated to be $15.8M which they considered to be conservative. This represents between 2% of the industry's revenue. If this figure was extrapolated to the UK market where we employs 2.1 million people in 250,000 companies and are responsible for 8.2% of Gross Value Added it could represent a proportionally larger number based on our more complex bespoke market.

5.2 *BIM level "1"*

Managed CAD Environment, this is the model which the vast majority of businesses are now seriously attempting to move into. The leading businesses including Laing were achieving good results in early production pilots in the early 1990's using these techniques and work they pioneered has resulted in the publication of the new BS1192:2007 and Avanti Processes.

5.2.1 *Endeavour house*

The Endeavour House project was the proof of concept of a government funded Partners in Technology (PIT) research project in partnership with Salford University. The project was based on research into the use of a 3D object model based Project Information Management systems including the use of a Project Extranet.

Two similar buildings had been constructed as part of BAA framework contracts with its supply chain. The object of the framework was to prove that project costs could be reduced if the learning of one project was passed onto the next and in particular when using the same team. This did not turn out to be true as the first building was delivered 25% over budget and the second, whose budget was reduced due to the perceived learning on the first, was delivered 25% over that cost.

For the third building it was decided to use a fully structured and managed process, based on the concept of a Project Information Model including a 3D object oriented project model.

The whole process of collection management and dissemination of the models, documents and information used a bespoke in-house developed collaboration tool (Project Extranet).

The project commercial performance identified a measured saving of 10% of final project costs. This included a 50% reduction in the contract growth seen on the previous two buildings.

5.2.2 *Heathrow express*

After the collapse of the tunnels on the Heathrow Express project BAA set up an innovation team to suggest better processes for the management of design information and project documentation. It set the scene for a totally collaborative process based around a 3D modelling environment including:

CAD and Documentation Standard Method and Protocol, A managed Single Model Environment, ISDN Collaborative network to site and printers, Electronic drawing management, 2/3D Modelling, integration and spatial coordination, Visualisation and Animation, early Virtual Reality Software.

The project identified savings of £720,000 on Printing with SME team. Saved 18% Drawing Production Costs and designed the signal sighting in a Virtual Construction Model. The project was delivered 3 weeks ahead of program. Measurements carried out by the client consultants conclude that the savings to the project were estimated in excess of 10% of the construction cost.

5.2.3 *Basingstoke Festival Place*

This project was a client led design team project with the contractor employed on a traditional JCT D&B contract. The contractor decided to build a full 3D model from the design teams checked, reviewed and signed off 'fit for construction' drawings/documentation.

The project also had a bespoke in house collaboration system available for model, document and project information control. No data management was attempted on this project. All errors and clashes identified in the model using Navisworks were recorded and RFI's were raised. The RFI's were not fully dealt with and the contract growth was approximately 25%. Some of the growth was due to client changes but some £10M was attributed to design ambiguity and represented 9% of the final construction cost that could have been avoided.

It was accepted that it would have been better if the design supply chain collaborated and produced the 3D models as part of the normal design development activity. However on those projects where the design teams do not have the required skills models built as a secondary activity are effective in reducing cost and risk. To build a model the investment is approx 0.5%–1.5% of the project cost with a reduction of 50% of the normal package growth of 25%. This equates to 10% of the final construction cost for material cost only.

5.3 *BIM level "2"*

5.3.1 *Enfield town centre project, London*

One of the first projects to employ the standards supported by Avanti was a multiuse development in Enfield, north London, designed by Reid Architecture. Funded by ING, it is £25 million of construction, largely retail / restaurant / health club users, but it also includes a civic facility incorporating council offices, a library and a public theatre. When Costain was appointed as the main contractor the decision was taken to adopt Avanti standards and operate in a shared model environment. Costain's bespoke extranet iCosnet was employed and the collaborative model was built using active .dwg files.

Critically, the team exchanged and built on live model files, the orientation, origin point and scaling of which were completely aligned, rather then swapping fragments of digital information, PDF's and / or frame (print) files appended to emails. The process of restructuring the previously completed CAD work to achieve this alignment required considerable concentration and effort but the benefits, according to Reid project architect Neil Sterling, far outweighed the initial irritation. Subsequent coordination of the work of subcontractors, all of whom were obliged to participate in using the system, was vastly simplified. Bourne Steel also used the model data, together with Revit software, as the basis for its own detailed modelling.

The 3-D expression of the shared model was facilitated, managed and updated by a third-party company employed by Costain called TruAxis Ltd. They assisted the team with the coordination activity, focusing on 3-D clash detection, but also provided construction sequence simulations (4D) that were used by Costain to improve the efficiency of construction programming. The model was also used as the basis for photorealistic renderings for marketing. The models were built using 3D object tools including Autodesk Architectural Desktop, Tekla, Multsuite and BS Link, with the various models brought together for coordination in Navisworks.

Costain claims that very considerable cost savings have been made by adopting a BIM approach. There were also very appreciable benefits experienced by the entire team associated with the clarity, simplicity and efficiency of use of the model for the everyday processes of information gathering, design creation and data exchange. The team estimates that at least 20 weeks were saved in the time needed to prepare information for issue to others.

5.4 *BIM level "3"*

As yet there are no true end to end implementations of iBIM as there are no production environments available to implement the IFC data exchange and the IDM process models are still under development. This does not mean however that no one has yet achieved great things with the technology in specific lines of business including the environmental market. Development is progressing rapidly and strenuous efforts are in place to bring the approach to the market.

5.5 *How can organisations adopt and benefit?*

Clearly as we have discussed there is an evolutionary approach to implementing BIM and organisations must be realistic as to their current capability and position in the evolutionary process. We have discussed some of the characteristics of the three key influencers in terms of people, process and technology and identified that there are significant benefits to be had at any stage in the adoption of BIM as long as it is done well. It is here that we meet the crunch, because as much as businesses can point at the lack of technology progress at the high end of the BIM model, the real issue is there are not enough good quality trained, "e-ready" businesses in the market to reach anywhere near critical mass at anywhere other that at the point we have named BIM Level "1". With a small but significant move underway to level "2", our key to success and evolution it to massively scale the industry up the ramp as quickly and as thoroughly as possible and in this the entire supply chain has an equal responsibility and potential return.

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Mapping between architectural and structural aspects in the IFC based building information models

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ABSTRACT: This paper addresses the problem of collaborative building design between architects and structural engineers. The discussed collaboration is based on the Industry Foundation Classes (IFC), currently the most popular and the most commonly used Building Information Model (BIM) specification in the Architecture, Engineering, Construction and Facility Management (AEC-FM) industry. Currently implemented solutions of collaborative building design between architects and structural engineers are based on pure geometry mapping. However the semantics of IFC based BIM enables more sophisticated solutions. Additional information extracted form the architectural model can be used in structural model generation. The centre of the proposed system presents a model server which allows semi-automatic extraction and transformation from architectural to structural model. Extraction and transformation are based on supplemented architectural to structural design view. A simple prototype has also been set up to prove the proposed concept.

1 INTRODUCTION

In the last two decades, the Architecture, Engineering, Construction and Facility Management (AEC-FM) community has allocated many research efforts in solving interoperability issues. As proved in practice, partial interoperability causes faults, delays, inadequate quality, low productivity and consequently additional expenses. Since artifacts are not uniquely specified (simple example: group of lines can have diverse meaning), further analysis and automation are disabled. Full interoperability defined as "Ability of two or more systems or components to exchange information and to use the information that has been exchanged" (IEEE 1990) can be achieved with focusing on (1) data sharing, (2) the ability to exchange usable information, and (3) platform independence, i.e. away from proprietary developments (Nour 2007).

The concept of Building Information Model (BIM) can be considered as the most suitable solution to achieve interoperability. BIM as a container of all information about the building in its lifecycle (to the arranged level of details) presents basis for structured information exchange. Eastman (1999) lists several BIM initiatives with different implementation success, but currently the Industry Foundation Classes (IFC) with numerous implementations and research projects seems to take over the BIM initiative.

In 1996 the International Alliance for Interoperability (IAI) introduced the first IFC specification release as a non-proprietary standard for the AEC-FM industry information exchange. STEP (STandard for Exchange of Product model data) based specification provides semantics as well as syntax together with exchange mechanisms for description of AEC-FM based product model. The IFC model defined by IAI Model Support Group (IAI-MSG) is based on structuralized approach where standard specification is publicly available before any software implementations. Layered model structure is used since it is not possible to define complete AEC-FM based product model in a single step. Such structure enables integration of arbitrary domain specific extension projects. Structural analysis domain for example has been defined in ST4 extension project.

IFC specification is already far too comprehensive to be implemented in its entirety. Therefore a small subset of entities based on the end user "use cases" is implemented. Described pragmatic approach is known as Model View Definition (MVD). Currently available IFC interfaces are compliant with extended coordination view which primarily deals with BIM geometry. Regardless to the MVD limited scope it is not reasonable to expect immediate perfect semantic interoperability. Many specification and implementation difficulties listed in (Bazjanac 2002) still have to be taken into the consideration and need to be solved in the near future.

2 PROBLEM BACKGROUND

2.1 *IFC specification aspects*

Architectural aspects are well covered in the IFC model (consequently also in extended MVD). This is not a particular surprise since the architecture domain has been included in the IFC specification form its first release. However structural analysis extension (ST4) of the IFC modeling framework does not cover all areas of structural design. Following features are considered in the current model scope: load bearing structure definition, planar and/or spatial structural analysis definition (with specification of structural submodels), definition of relationship between the existing building elements and elements of structural model, simple analysis results – forces and displacements. Currently out of scope are information related to dynamic analysis, definition of prestressing, stability problems and detailed description of finite elements topology used in numeric computation (Weise et al 2003). Therefore only partial description of general structural model is possible. Building elements (described with abstract entity IfcBuildingElement) are not directly suitable for description of structural elements and consequently new classes had to be defined to deal with specific requirements of structural analysis domain. Definition of new abstract entity IfcStructuralItem enables principal separation of building elements from their mechanical representation(s) and consequently offers possibility to overcome possible semantic differences (individual beam in architectural model vs. continuous beam in structural model).

ST4 extension defines special relationship entity "IfcRelConnectsToStructuralMember" which should accomplish the integration of structural representation into the project repository. Multiple instances of presented entity can therefore be used to reflect the many-to-many nature of the association between physical and analytical elements. This entity presents an essential element in preservation of relations between architectural and structural model.

2.2 *Statement of the problem*

The building design process is by its nature iterative inside the same discipline and also between other AEC-FM disciplines. The delivery of architectural design to structural design presents an obvious general example. In the AEC-FM common practice the architectural design deals with the architectural aspects while the structural design focuses on mechanical properties and behavior of the structure. Only BIM based design ensures lossless information handover

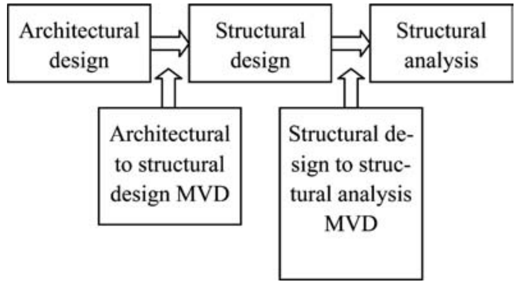

Figure 1. Model view definition in structural design and analysis domain.

from one sub-model. Described procedure eventually results in iterative design process commonly marked as roundtrip engineering.

Currently IFC interfaces presents the most widely used interoperability solutions, regardless to well known deficiencies of file based exchange (file size, model versioning, provenance data, etc). Most commonly used architectural design applications (Archicad, Allplan, Revit, etc) already contain IFC interfaces. Most of them are compliant with extended MVD and some of them are also certified according to the official IAI certification procedure.

IFC based BIM modeling in structural design and structural analysis domain is not yet clearly defined. According to the MVD group (IAI-MVD 2007) two domain specific views should be defined: architectural to structural design MVD and structural design to structural analysis MVD (Figure 1). Architectural to structural design MVD should cover only information created by the architect. According to the proposal of this view (no exact definition is available) the product geometry should present the central point of interest. Furthermore, structural design to structural analysis MVD should contain the list of entities to be exchanged inside structural design and analysis. Mapping between architectural and structural MVD is outside of its definition scope and therefore has to be defined separately.

Poor IFC implementation in structural design and analysis software is not a particular surprise since current IFC specification does not include debated MVDs. It should also be pointed out that currently most of structural analysis applications are also compliant only with extended MVD which does not include any entities from structural analysis extension. Therefore each integrated IFC interface has to map entities of architectural model to the native structural application primitives. Presented mapping is application specific. Within such approach structural engineers are limited to the pre-defined interface specific mapping which commonly results in too detailed 3D structural model (too detailed for preliminary design phase where only approximate dimensions are required). According to the IFC ST4 extension structural engineer should not be forced to use spatial structures only because 3D architectural model exists in the background. IFC specification allows definition of multiple structural models inside single BIM. Even more – it is possible to select the best fitting for structural representation(s) for each individual architectural element, depending on the specific analyses needed.

The idea of this paper is to propose a server based system that would allow deduction of topological relationships among different building elements for creating structural model from corresponding architectural model. Specific load bearing building elements have to be extracted from the IFC building information model and according to encoded heuristic rules transformed to the IFC structural members. The relationships between building elements are also used to deduce mechanical connectivity between structural elements. Support conditions, missing mandatory attributes of structural members and other structural characteristics have to be defined additionally. Proposed system has to ensure the consistency of sub-models and solve information ownership. Since the use of IFC interfaces can not solve stated issues, IFC model server will be used as a potential solution.

2.3 *Related work*

Mapping between sub-models in IFC specification became the point of interest soon after the first implementations. First research projects were focused only on general building geometry mapping. Ronneblad and Olofsson (2003) for example demonstrated IFC based geometry information exchange between architects and precast concrete designers.

Romberg et al (2004) introduced a computer aided method supporting co-operation between architects and engineers on basis of three dimensional model based on IFC specification. Proposed algorithm extracts model geometry in three steps: After one of various geometric representations (but not bounding box) is extracted from the IFC model, intermediate model (consistent and corrected) is generated. In the next step ACIS based geometric model is decomposed into a connection model which is furthermore subject of an automatic numerical discretization with a p-version of the finite element method. Presented research uses the IFC model only for geometry information extraction. Finite element method (FEM) can not be described in terms of IFC model since its description is currently out of IFC scope. Added value of FEM generation is also doubtful since majority of structural analysis software already contains complex automatic meshing algorithms.

The construction of the structural model from IFC-based architectural model has also been proposed by Chang et al (2006). The presented research characterizes architectural components of IFC model as a physical building model which can significantly differentiate form FEM based structural model. Regardless to the IFC structural extension, new XML based format for description of structural model is proposed. Therefore additional transformation is needed in order to import the model in selected FEM application. The extraction and the aggregation of structural building elements (walls, columns, beams and slabs) is performed on the proposed IFC structural model server in conjunction with the implemented IFC schema.

IFC based model server for web-enabled collaborative building design between the architect and structural engineer has also been developed at Nanyang Technical University in Singapore (Chen et al 2005). This research presents the most sophisticated server based mapping solution where actor roles, their privileges and sequence of tasks are exactly defined. The current implementation of the server system supports the automatic transformation of designed model contents (only column and beams) and the representation from the architectural domain to structural domain. Model mapping is again limited. Only geometry aspects of structural model are covered and a new XML based format is proposed to describe a structural model.

3 SOLUTION CONCEPT

As described in ST4 project documentation (Weise et al, 2002) a mechanical model mapped form the architectural model should include information about (1.) idealized structural elements, (2.) nodes – mechanical connectivity, (3.) supports, (4.) mechanical properties, (5.) loadings, (6.) other information. All related research work (Chen et al 2005, Deng et al, 2006, Romberg et al 2005) is based on assumption that only idealized structural elements and connectivity can be deduced from IFC based architectural model. However IFC based architectural model can indirectly contain much more than just geometry information (the occupancy of spaces, façade systems, floor system, roof system, etc) which can be furthermore used in creation of a structural model. The concept of retrieving additional information from IFC semantic context will be proved in the “Prototype” section with simple example: Imposed structural load can be determined from the occupancy of spaces and from the corresponding Eurocode standard and automatically assigned to the structural members.

The proposed solution aims to increase effectiveness in the building design process with the implementation of IFC specification and web enabled building design between architects and structural engineers. As presented in the use case diagram (Figure 2) the discussed solution involves three main actors: an

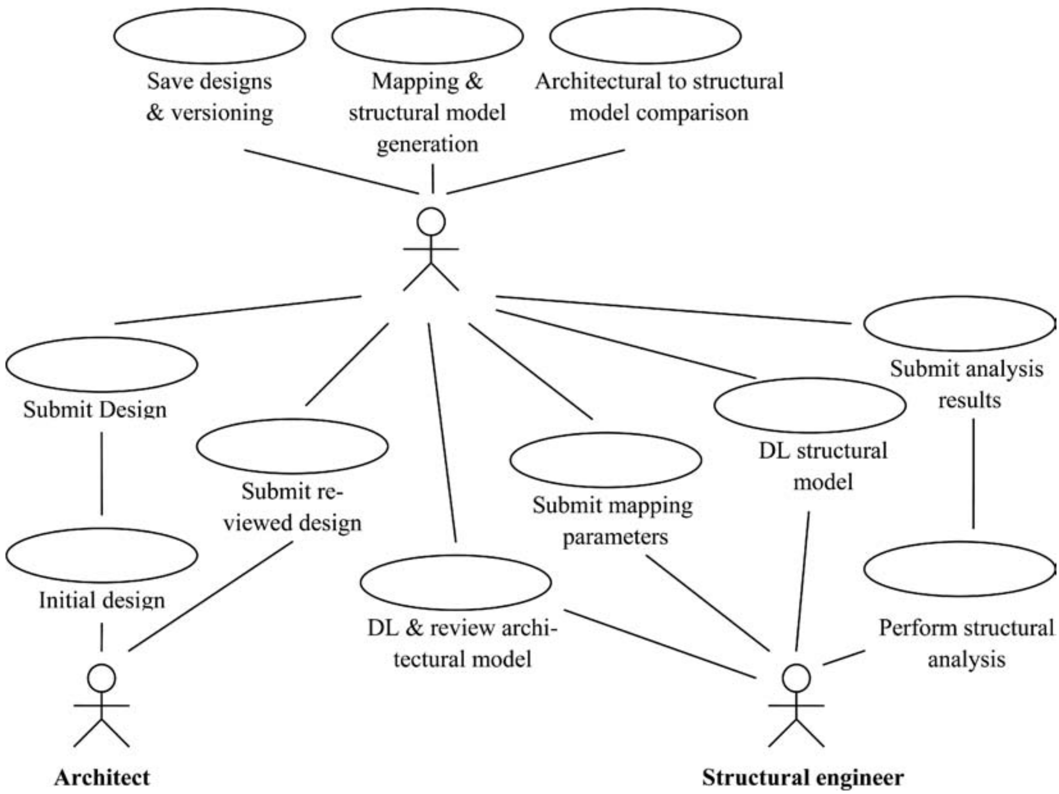

Figure 2. Use case diagram.

architect, a structural engineer and a server. The current practice omits the server and other two parties have to take care of its tasks. General building design process is triggered when the architect finishes his work and saves design as IFC model.

It has also be taken into consideration that IFC interfaces of architectural design applications most commonly implement only coordination MVD, which cannot satisfy the exchange requirements. As discussed in previous chapter new architectural to structural design MVD has to be defined.

The coordination MVD presents an appropriate origin point for definition of the architectural to structural MVD. Information about the following building elements and spatial container elements should be exchanged: beam, column, covering, member, plate, proxy, ramp and ramp flight, roof, slab, stair and stair flight, project, site, building story and space. Due to the paper limitations details about material and representation related items will be omitted.

However two additional entities should be exposed. Not all building elements used in architectural model have a load bearing purpose. Specific IFC entities (IfcBeam, IfcColumn, Ifc Slab, IfcWall and their sub-entities) have a "common" property set (Pset_BeamCommon, Pset_ColumCommon, etc). Each property set contains the property "LoadBearing" which can be used to distinguish whether the element has structural purpose or not. This property set should also be included in the proposed view although its Boolean value should be assigned by structural engineer in the first roundtrip engineering iteration. Furthermore it is not necessary that the same primitive information (in terms of points in space, solids, etc) should be used in definition of spaces (zones) and building elements. Therefore the definition of relationships (IfcRelAssignToProduct) between spaces and building elements in architectural model is mandatory.

The IFC model prepared according to proposed MVD can be uploaded to IFC model server. Only an architect has the privilege to upload architectural models. Mapping based on predefined relations between building and structural elements is not performed directly after uploading the architectural model. The implemented algorithm waits for the structural engineer to react. After security checking, the structural engineer can check the architectural design and can input the additional information about analysis that he would like to perform (space frame, plane frame, etc.)

Depending on the structural system, different mapping algorithms can be applied. Regardless to the used algorithm, the following aspects of IFC specification have to be taken into consideration. IFC structural extension (ST4) uses topological approach to describe the structural model. Complex data models (like IFC model) in general could significantly be simplified if the amount of information represented is reduced into primitive data, where more complex data can be deduced and extracted. In the IFC based BIM entities describing the geometry of architectural model present basic or primitive data. The number of all possible topological relationships among building elements primitives (separation, adjacency, containment, connectivity and intersection) is in structural model generation reduced to locate connectivity and intersection between elements. Extruded solids are for example used for geometric representation of building elements (columns and beams). Line segment that connects central points of the two end cross-sectional surfaces presents corresponding structural representation. Unfortunately mapping is not always so simple. To completely define a topology of structural model, the following algorithm should be applied: 1.) Analysis of connections/intersections between building elements. 2.) Definition of idealized structural elements. 3.) Definition of joints between structural elements. Detailed description of topological relationships between building components and detailed algorithm can be found in (Nguyen & Oloufa 2002). The suitability of the proposed algorithm for discussed mapping has also been confirmed with its implementation in related research projects (Chen et al 2005).

When new structural elements are created, their relation to building elements should be preserved. GUID (Genuine Unique Identifier) offers a unique possibility to preserve stated relations which proved to be mandatory in the roundtrip design. Since the load definitions mostly refer on architectural model (floor, balcony, residential area, location of the building, etc), the preservation of relationships between building and structural elements also proved to be mandatory in the semi-automatic load assignment. Simple example to prove the concept: the occupancy of spaces and corresponding slabs are extracted from the architectural model. Since the relation between slabs in the architectural model and slabs in the structural model is also preserved, the imposed load on floors can automatically be assigned to related structural members.

Information retrieved form the Eurocode standard has to be transformed into interpretable form. XML based format is proposed to capture the discussed information. Figure 3 presents simple example referring to imposed loads. Due to the specific characteristic of load groups defined in Eurocode (imposed load, wind, snow, etc) separate XML based description are proposed.

```
<?xml version="1.0"?>
<DATA>
<EC loads - simple example>
        <category ID="A"
                <subcategory ID_S=A1>
                <load>2.0</load>
                </subcategory>
                <subcategory ID_S=A2>
                <load>2.0</load>
                </subcategory>
                <subcategory ID_S=A3>
                <load>2.5</load>
                </subcategory>
        </category>

        <category ID="B"
                <subcategory ID_S=B1>
                <load>3.0</load>
                </subcategory>
        </category>
        <category ID="C"
                <subcategory ID_S=C1>
                <load>3.0</load>
                </subcategory>
                <subcategory ID_S=C2>
                <load>4.0</load>
                </subcategory>
                <subcategory ID_S=C3>
                <load>5.0</load>
                </subcategory>
                <subcategory ID_S=C4>
                <load>5.0</load>
                </subcategory>
                <subcategory ID_S=C5>
                <load>5.0</load>
                </subcategory>
        </category>
        <category ID="D"
                <subcategory ID_S=D1>
                <load>4.0</load>
                </subcategory>
                <subcategory ID_S=D2>
                <load>5.0</load>
        </category>
</EC loads - simple example>
</DATA>
```

Figure 3. Imposed loads in XML.

After a successful mapping the structural engineer can download the structural model, import the model in any IFC compatible structural analysis model, define the missing components and performs structural analysis. The analysis results can again be exported and uploaded to IFC model server. Due to the preserved relationship between architectural and structural elements, their common properties (location and cross section) can be compared. If there is a discordance determined, an architect should update architectural model (structural engineer is not authorized to do it) and – if necessary – next stage of roundtrip design should occur.

4 PROTOTYPE

Our goal was to create a non-proprietary solution. Unfortunately the only available non-proprietary solution presented by Adachi (2002) was proved to be insufficiently documented and outdated technology depended. Therefore a new IFC model server solution has been developed using PHP (version 5.2.0) with MySQL (version 5.0.32) on a Debian based Apache 2.2.3 server. MySQL database has allowed us to make complicated entity related queries and PHP has proved to be a powerful tool for parsing physical file and manipulating records in the database.

A full web interface with person and role based authentication was developed which allows access through the internet from any location. Due to the limited resources only a segment of proposed collaborative design has been implemented in the prototype. Currently the prototype is built in a way that physical files are uploaded to the server using HTTP/1.1 method POST, processed/parsed using PHP5 Hypertext Preprocessor programming language and then uploaded to the server. After all transformations are complete, the resulting file is saved to the server and is available for downloading. Out of various loads defined in the Eurocode standard (ENV 1991 2005) only imposed loads on floors, balconies and stairs on building are currently implemented in the prototype.

IFC based architectural model presents the basis for a collaborative building design. Archicad IFC 2×3 interface has been used in presented test case (Figure 4). In general any other IFC compatible architectural design application that uses solid modeling approach in primitive geometry description and that preserves relations between entities describing building elements and spaces (zones) could be used. After the architectural design is complete, the architect uses application specific IFC interface and exports the model as IFC model. Then he logs to the server and submits his design (Figure 5). The server is now in the intermediate state waiting for the structural engineer reaction. The structural engineer should – after successful security checking – first examine the architectural model, input additional analysis parameters and then trigger semi-automatic mapping form architectural to structural model. After predefined mapping is complete, the structural engineer can download IFC based architectural and structural model (Figure 7), complete the structural model and perform structural analysis.

AxisVM structural analysis software has been used in presented research due its robust graphic CAD interface, intensive analysis efficiencies and mainly because of its full IFC compatibility (Figure 7). The presented software is one of rare IFC compatible structural design and analysis tools that regardless to their domain covers the architectural and structural aspects of IFC model. Majority of IFC interfaces of structural design applications are capable of handling only basic entities defined in coordination MDV. When importing downloaded IFC model in AxisVM, the structural engineer can import architectural and – if available – structural model. If structural model is selected, then "IfcStructuralItems" are recognized as AxisVM primitives (elements, nodes, loads, etc).

Only missing loads, cross section characteristic, supports and material information should be

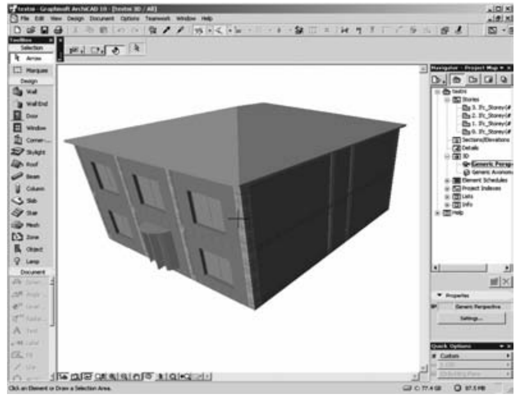

Figure 4. Architectural model in Archicad.

Figure 5. IFC model server web interface.

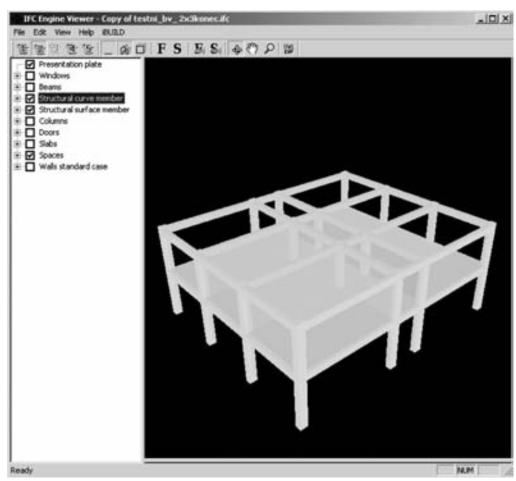

Figure 6. BIM architectural and structural components.

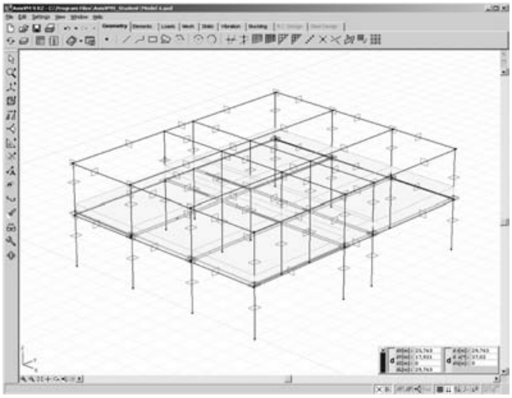

Figure 7. IFC based structural model imported in AxisVM.

additionally assigned. But if architectural model is selected, then only the geometry is mapped. All other information relevant to structural design and analysis have to be assigned manually.

Presented mapping between architectural and structural model presents the first step in the iterative collaborative building design. After structural analysis is complete, its results should be mapped to IFC model and references between architectural and structural model should be updated. However this is not possible due to the unpredictable behavior of Archicad and AxisVM IFC interfaces referring to the GUID management. Unique identification of BIM primitives (IfcBuildingElements in architectural model and IfcStructuralMembers in structural model) is enabled due to inappropriate GUID management in both used applications. Attempts to find a solutions with assigning optional attributes also proved to be inefficient (optional attributes also do not preserve their value). Although there might exist some other alternative solution, the development of the presented prototype was intermitted at this stage.

5 DISCUSSION/CONCLUSION

As proved with the presented research, the semantic context of BIM offers much more than just geometry extraction and/or transformation. With reference to Eurocode standard some of mechanical model loads can also be deduced from IFC based architectural model. Support conditions and additional mechanical properties need to be input externally. Although only a small segment of semantic context was used in the prototype, presented solution proves stated concepts. We could conclude that IFC specification theoretically present an appropriate grounding for the efficient collaborative design work between architects and structural engineers. However the experiences gathered in prototype development indicates the opposite.

This research opens a huge number of interest research topics. Since only a fragment of loads defined in ENV 1991-1 standard has been used in the prototype, a special study should be undertaken to define more complex XML based specification. The transformation from architectural to structural model is not a trivial process. The presented geometry based transformation could be supplemented with more complex heuristic rules which could capture structural engineers' knowledge about transformations. The additional improvements of the server could also be done in the future. A SOAP based web service, enabling the prototype to communicate with any SOAP compliant client, would allow partial model exchange.

The concept of the semantic context and re-use of the information captured in IFC based BIM could furthermore be applied to other domains (architectural design to thermal analysis, etc). According to the experiences gathered in the presented research work we dare to clam that without clearly defined IFC model views and/or useful minimums any practically implemented research work will be limited only on prototype solutions.

Instead of the summarized research findings this paper will be closed with general opinion about IFC specification and is implementations. After more than ten years of existence and several releases, the performance of IFC specification and appurtenant interfaces is not satisfying and still can not be compared with proprietary based interoperability solutions. Regretfully it has been proven that regardless to successfully passed certification process IFC interfaces do not match specification requirements. Inappropriate GUID management, diverse modeling approaches and undefined model views present the key deficiencies of IFC specification and its implementations.

Therefore instead of developing new specification extensions, a complete IFC specification review should be done. As established in presented research, more detailed instructions for implementation with clearly defined views should also be provided from specification authors. Only mature and better implemented specification will be able to compete with similar proprietary solutions.

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eServices and SOA for Model-driven cooperation in AEC

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

A distributed portal-based platform for construction supply chain interoperability

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ABSTRACT: Collaboration and interoperability plays a very significant role in a construction supply chain. The lack of information sharing and software interoperability hampers coordination and collaboration among project participants, which are crucial to the success of a supply chain. As the Internet becomes ubiquitous and instantaneously accessible, the web services model has emerged as a promising approach to support supply chain collaboration and achieve interoperability. This paper discusses a web service framework to connect, invoke and integrate loosely coupled, heterogeneous information sources and software applications. Specifically, web portal technology is leveraged to implement the web services platform and to provide a robust and customizable user interface. The issues of information ownership rights and proprietary privacy may hinder information sharing among companies in a centralized portal system. A decentralized portal network architecture is introduced to promote sharing of information and to enable distributed computing. This paper presents the prototype web-based platform, *SC Collaborator*, that is designed to support data exchange, information sharing and supply chain collaboration. The platform leverages open source technologies and implements the proposed distributed portal network architecture. Two example scenarios are included to demonstrate the potential of the SC Collaborator system in managing information flows in AEC activities and facilitating interoperability.

1 INTRODUCTION

Construction supply chains are highly fragmented in nature. The scattered information sources and hardware platforms pose a challenge to the establishment of data exchange and communication channels in the architectural, engineering and construction (AEC) industry (Lee & Bernold 2008). Integrating information and software functionality in a multi-participant supply chain is a non-trivial task because project participants may use different hardware platforms and software applications. To facilitate the coordination of information flows within and across companies participating in a supply chain, the interoperability issue among distributed hardware platforms, software applications and information sources must be addressed. The purpose of interoperation is to increase the value of information when information from multiple and, likely, heterogeneous sources is accessed, related and combined. Interoperability allows data exchange and sharing among heterogeneous information sources, software applications and systems. Therefore, interoperation can add significant value to each individual source and application, as well as enhances efficiency and performance of a supply chain.

The lack of interoperability leads to significant economical costs in various industries. According to a study by NIST, in the year 2002 alone, inefficient interoperability costs more than $15.8 billion to the construction industry on the design, construction and maintenance of large commercial, institutional and industrial buildings (Gallaher et al. 2004). Another study by NIST estimates that imperfect interoperability costs the US automotive industry about one billion dollars per year (Brunnermeier & Martin 2002). Creating interoperable networks to support data exchange and communication among software applications can be expensive. As reported in Bingi et al. (2001), organizations continuously spend up to 50 percent of their IT budgets on application integration. Insufficient interoperability also hinders project efficiency and coordination. Lack of information sharing and application integration results in the myopic control in a supply chain. Project participants work in an isolated manner and do not have a macroscopic view of the whole supply chain. The participants make their own decisions to optimize their costs or benefits, based on the information from the immediate downstream node in the supply chain. As a result, the whole system may not achieve the optimum performance even though

Figure 1. SC Collaborator viewed in web browsers.

each project participant optimizes its own performance (Yu et al. 2001). This myopic view may also lead to information distortion among supply chain partners. In the procurement process, for example, as individuals attempt to forecast and make decisions based on the information from the immediate downstream node only, demand signal amplification and variation tend to increase as one moves upstream – a phenomenon termed "bullwhip effect" (Lee et al. 2004). Therefore, sharing of information and collaboration between each party is crucial to the success of a supply chain (Gunasekaran & Ngai 2004, Lee et al. 2000). Supply chain interoperability enhances the performance of construction projects in terms of quality, time, cost and value.

The issue of interoperability can be tackled on two levels, namely, information interoperability and software interoperability. To facilitate data sharing and information interoperability, much efforts have been spent to build unifying standard models of concepts and definitions such as Industry Foundation Classes (International Alliance for Interoperability 1997), CIMSteel Integration Standards (Watson & Crowley 1995) and BIM (Brucker & Nachtigall 2005) to capture various phases and facets of design and construction processes. In practice, software services that need to communicate will likely be based on distinct ontology or data models and structures, that reflect the contexts and vocabularies for specific applications and domains (Ray 2002). Efforts have been attempted to "harmonize" different information ontological standards (Begley et al. 2005, Cheng et al. 2008, Cheng et al. 2002, Lipman 2006). This paper focuses on software interoperability to facilitate the connectivity, deployment and integration of distributed information sources and engineering services.

In this paper, we will first review the current approaches to integrate information, applications and services into workflows and supply chains. The proposed service integration framework which leverages web services model and web portal technologies will then be discussed. We will present a prototype platform, *SC Collaborator* (Fig. 1), that is designed to support interoperation and collaboration in AEC supply chains. Two example scenarios will be included to demonstrate the potential use of the prototype system for the management of information flow in AEC supply chains.

2 INTEGRATION OF INFORMATION, APPLICATIONS AND SERVICES

Information and software applications can be integrated in a local machine relatively easily. Sharing and exchange of information can be performed across applications as long as application programming interface (API) is available for the mapping applications. Invocation and integration of software functionality are also allowed for some applications through their APIs. In a supply chain, however, companies and project participants are geographically distributed and employ different hardware platforms and software applications. Mechanisms which support the integration of information and applications in a local machine do not facilitate interoperability in a supply chain. Some companies establish communication networks using standards such as Electronic Data Interchange (EDI) to connect with partners. However, the implementation of such communication network infrastructures can be very expensive and is not economically feasible for small to medium businesses, which are common in the construction industry. In addition, the long configuration time and rigid system architecture do not provide the flexibility needed to support fast changing construction supply chain.

With the rapid development of web technologies, the Internet has become ubiquitous and instantaneously accessible. The proliferation of the Internet makes it the most cost effective means of driving supply chain integration and information sharing (Lee & Whang 2005). Companies increasingly take advantage of the Internet and information technology to create a virtual e-chain to communicate and collaborate with other supply chain participants (Manthou et al. 2004). Various efforts have been made to leverage the Internet for information and service integration, engineering simulation, negotiation and cooperation, collaborative planning and design, and other supporting activities (Anumba & Duke 1997, Cheng et al. 2001, Cheng et al. 2006, Danso-Amoako et al. 2006).

The web services model has emerged as a promising approach to connect and aggregate distributed web applications and information sources. Utilizing the Internet as the communication network, a "web service" can be described as a specific function that is delivered over the web to provide information of services to users. Information sources and software applications can be packaged into individual web service components. Leveraging well established Internet protocols and commonly used machine readable representations, web services can be located, invoked, combined and reused. The implementations of web services are encapsulated and not exposed to the users. Changing the implementation of one web service function does not alter the way that the users invoke the function. This enables clean and robust deployment and maintenance of web services. With the service oriented architecture, the web services model allows a large complicated system infrastructure to be built in a scalable manner. Modular system development and maintenance is enabled as the system is divided into web service components which can be managed separately. The web service components can be plug-and-played to cater different project requirements at each project stage. The reusability of the components also reduces the time and efforts to develop similar components.

There are many existing mechanisms to deploy, invoke, orchestrate and terminate web services for web-based integration (Cheng 2004, Danso-Amoako et al. 2006, Greenwood et al. 2004, Ismail et al. 2002). Various languages have been proposed to facilitate the discovery, execution and composition of web services. Examples include Web Services Description Language (WSDL) (Booth & Liu 2004) and Flow Language (WSFL) (Leymann 2001), Business Process Execution Language for Web Services (BPEL4WS) (Andrews et al. 2003), and Web Service Ontology based on DARPA Agent Markup Language (DAML-S) (Ankolekar et al. 2001). Semantic web services have also been an active area of research and development (de Bruijn et al. 2005, Preist 2004).

3 DISTRIBUTED PORTAL NETWORK

3.1 *Centralized service integration*

Web portal technology has been used to aggregate scattered, distributed information, applications and processes across organizational boundaries. A web portal system provides the clients a single point of access to information and applications regardless of their location or storage mechanism. Through the portal system, multiple applications can be accessed, related and integrated into a workflow or a supply chain. It provides a centralized storage of information and a unified hub to the integrated information, applications and services. Clients can access to multiple systems or applications via the web portal with a single registration and authentication.

The web services model can be implemented using a web portal system. Applications and information sources are wrapped and deployed as individual web portlets, which are web service units that a web portal system can integrate and reuse. Web portlets are subprograms that encapsulate a single or a number of web applications. They are contained in a portal system and become visible and accessible via the portal system. The sessions and user preferences of each portlet are also stored and managed in the portal system.

3.2 *Decentralized network architecture*

Web portal technology has been deployed by companies for information management and sharing. Web portals are commonly used as content management systems (CMS) and web publishing tools to store digital contents and share them with other project members (Michelinakis 2004). Portal systems therefore act as a centralized repository of information and documents. Some companies build an intranet using web portals. It allows the users to access sensitive internal information and applications, and the administrator to manage a huge amount of information at a centralized location. Both the usages as repository and intranet require a central server and database to support the operations of a centralized portal system. This is not practical for supply chain collaboration due to the issues of information ownership rights and proprietary privacy. Companies prefer having their own database system and if necessary, exposing sensitive information such as profit margin only to specific supply chain members at a specific period of time. The use of a central database eliminates the incentive to information sharing across organizations. In this work, a distributed extranet network architecture across organizations is proposed for supply chain integration.

In the distributed network architecture, each organization has its own database and portal system. The portal system can act as an intranet and CMS internally, while at the same time allows information exchange and sharing over the web. As illustrated in Figure 2a, a single portal system is conventionally used to integrate loosely coupled applications and to share information among project participants from different organizations. The database and the portal system are hosted by either one organization or a third party company. With the centralized architecture, individual organizations may hesitate to upload and share their sensitive information depending on their level of trust. On the contrary, the network architecture shown in Figure 2b distributes the storage and ownership of information among enterprises and users. They can grant the rights to view or access their own proprietary data and documents to particular collaborating partners for a specific period of time. The distributed system thus provides better control of the shared information. Enterprises may become more willing to coordinate and share their proprietary information.

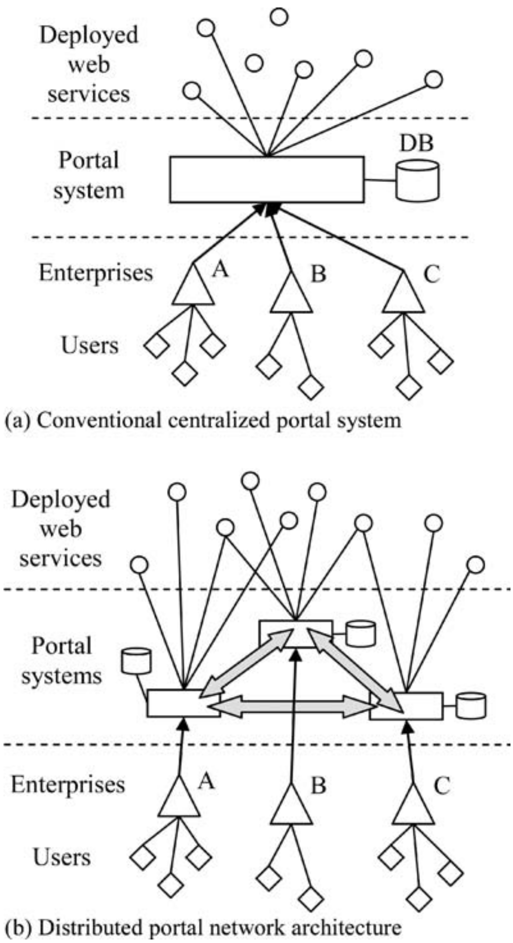

Figure 2. Conventional portal usage versus distributed portal network.

4 SC COLLABORATOR

SC Collaborator is a web-based prototype platform that is designed to support interoperation and collaboration among project partners in the construction industry. The platform integrates distributed information sources and engineering services using the web services model. SC Collaborator provides an economical solution to construction supply chain integration by adopting open source technologies. Web portal technology is leveraged to provide the users a customizable user interface. The system implements the distributed portal network architecture discussed in Section 3 with security access control. In the following sections, the system architecture of SC Collaborator will be discussed. Two illustrative scenarios will then be presented to demonstrate the interoperation among general contractor, subcontractors and suppliers using SC Collaborator.

4.1 *System architecture*

Figure 3 shows the system architecture of SC Collaborator. On the server side, SC Collaborator is divided into three tiers – the web server/servlet container tier, the business implementation tier and the database tier. The servlet container tier allows clients to access the system through standard web services protocol by SOAP messaging and WSDL description, through wireless devices by Wireless Markup Language (WML), or through web browsers. The business implementation tier provides connectivity to the database, manages the sessions of the system, manages the information transaction, and performs business functions. The database tier serves as the back-end information source to support the whole platform. It stores information such as user privileges and settings, portal and portlet configurations, and page layout settings. The three tiers of SC Collaborator are implemented with open source software – Apache Tomcat, Liferay Portal and MySQL. SC Collaborator provides an economical and desirable platform for the AEC companies, which are usually small to medium in size and are often reluctant to invest on a system that requires frequent changes.

The business tier consists of the Plain Old Java Object (POJO) implementation core and two supporting frameworks, which are all bundled in the Liferay Portal (*Liferay Portal Enterprise* 2007). The POJO implementation core performs the main computational job. The core can connect to other localized applications through APIs or other remote applications via web services. The core is extended with two light-weight frameworks, Hibernate and Spring. The Hibernate framework maps the objects in the relational database into Java object-oriented classes. The Spring framework wraps the POJO core and provides additional features such as messaging, session management and transaction management.

4.2 *Distributed portal network*

Each individual SC Collaborator system is a portal platform which can act as a digital content repository or as an intranet managed and hosted by separate organizations. The portal platform provides the clients a single point of access to information sources and applications. A single authentication of the system allows clients to gain access to multiple systems or applications with a unified and customizable user interface. The entire system can be divided into web portlets which can be developed, managed and integrated independently, that makes the system flexible, scalable and easily re-configurable.

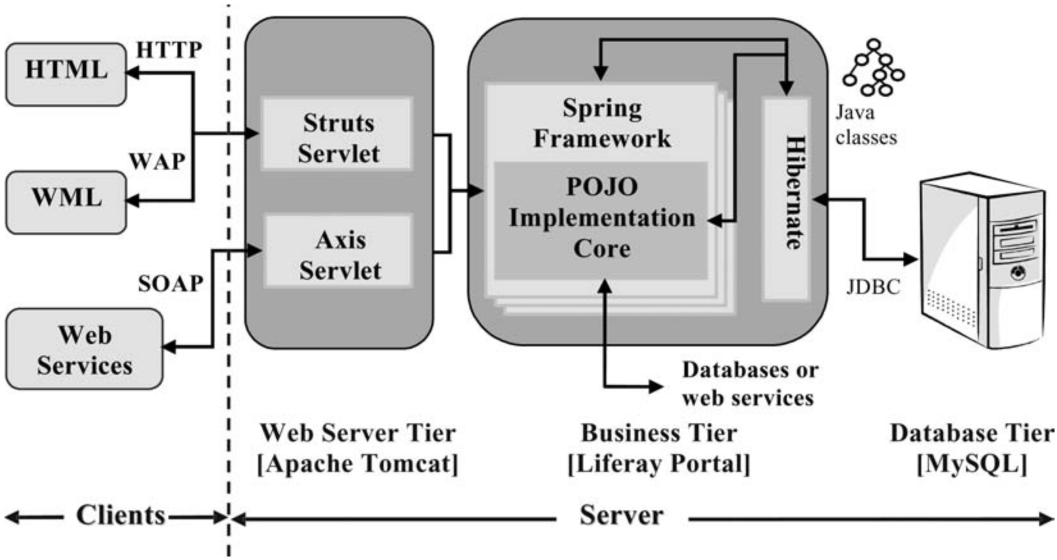

Figure 3. System architecture of SC Collaborator.

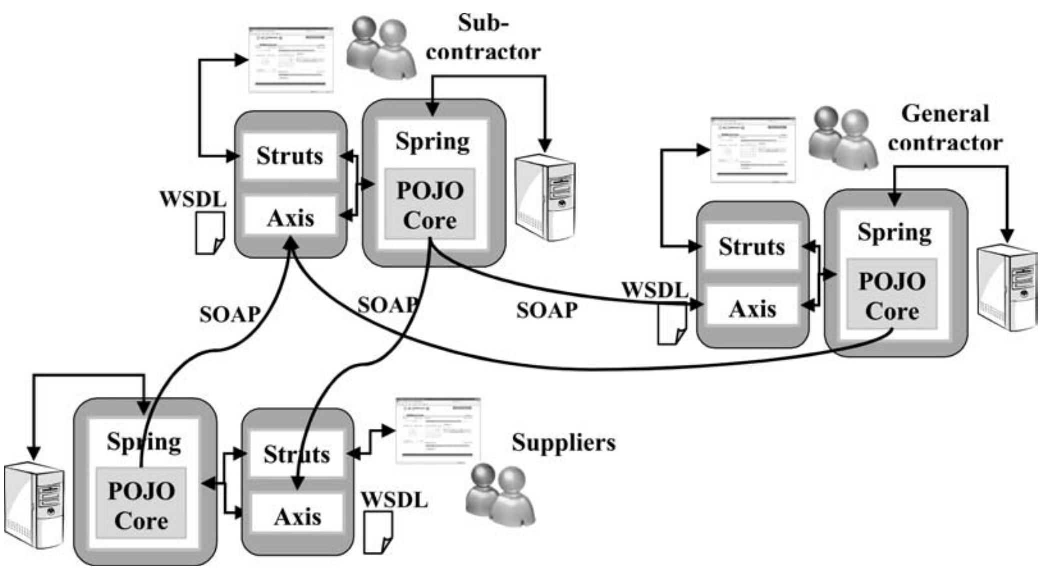

Figure 4. Communications among individual SC Collaborator systems.

SC Collaborator implements the distributed portal network introduced in Section 3. The communication between individual SC Collaborator systems is achieved using standardized web service technologies and languages (Fig. 4). The POJO implementation core extended with the Spring framework supports the invocation of web services by SOAP. The Axis servlet allows portal and portlet functionalities to be exposed and deployed as web services. The deployed functionalities are described using standardized WSDL language for discovery and invocation. Figure 5 shows the WSDL file of a simple portlet functionality which sends purchase orders to suppliers. The connectivity between separate SC Collaborator portal systems can be easily created as long as the address of the deployed web services is given.

```
<?xml version="1.0" encoding="UTF-8" ?>
- <wsdl:definitions
    targetNamespace="urn:http.service.material_buyer.portlet.ext.com"
    xmlns:apachesoap="http://xml.apache.org/xml-soap"
    xmlns:impl="urn:http.service.material_buyer.portlet.ext.com"
    xmlns:intf="urn:http.service.material_buyer.portlet.ext.com"
    xmlns:soapenc="http://schemas.xmlsoap.org/soap/encoding/"
    xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/"
    xmlns:wsdlsoap="http://schemas.xmlsoap.org/wsdl/soap/"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  + <!--    -->
    <wsdl:message name="addPurchaseOrderResponse" />
  - <wsdl:message name="addPurchaseOrderRequest">
      <wsdl:part name="orderId" type="xsd:string" />
    </wsdl:message>
  - <wsdl:portType name="MaterialBuyerServiceSoap">
    - <wsdl:operation name="addPurchaseOrder" parameterOrder="orderId">
        <wsdl:input message="impl:addPurchaseOrderRequest"
          name="addPurchaseOrderRequest" />
        <wsdl:output message="impl:addPurchaseOrderResponse"
          name="addPurchaseOrderResponse" />
      </wsdl:operation>
    </wsdl:portType>
  - <wsdl:binding
      name="Portlet_MaterialBuyer_MaterialBuyerServiceSoapBinding"
      type="impl:MaterialBuyerServiceSoap">
      <wsdlsoap:binding style="rpc"
        transport="http://schemas.xmlsoap.org/soap/http" />
    - <wsdl:operation name="addPurchaseOrder">
        <wsdlsoap:operation soapAction="" />
      - <wsdl:input name="addPurchaseOrderRequest">
          <wsdlsoap:body
            encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
            namespace="urn:http.service.material_buyer.portlet.ext.com"
            use="encoded" />
        </wsdl:input>
      - <wsdl:output name="addPurchaseOrderResponse">
          <wsdlsoap:body
            encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
            namespace="urn:http.service.material_buyer.portlet.ext.com"
            use="encoded" />
        </wsdl:output>
      </wsdl:operation>
    </wsdl:binding>
  - <wsdl:service name="MaterialBuyerServiceSoapService">
    - <wsdl:port
        binding="impl:Portlet_MaterialBuyer_MaterialBuyerServiceSoapBinding"
        name="Portlet_MaterialBuyer_MaterialBuyerService">
        <wsdlsoap:address location="http://171.67.80.217:8080/tunnel-
          web/axis/Portlet_MaterialBuyer_MaterialBuyerService" />
      </wsdl:port>
    </wsdl:service>
</wsdl:definitions>
```

Figure 5. Example WSDL file deployed in SC Collaborator.

Security is an issue that many companies concern for collaborative systems. The portal and portlet functionalities can be deployed as web services in a secure way in SC Collaborator. Successful authentication with correct user ID and password is needed to invoke the web services. The user ID and password share the same profile with the accounts in SC Collaborator. In other words, the system administrator can manage the access rights to the deployed web services by managing the accounts in SC Collaborator using the administrator portlet. The access rights are established or removed when the corresponding SC Collaborator account is created or deleted. This ensures a consistent access control to the portal system as well as the exposed functionalities.

4.3 *Example scenarios*

To illustrate the SC Collaborator platform for the applications in the AEC industry, two example scenarios are described in the following sections. In the two examples, distributed SC Collaborator system is installed in each organization. These examples demonstrate the potential of using SC Collaborator to connect distributed web applications and systems, and to act as a unified communication channel among construction project participants.

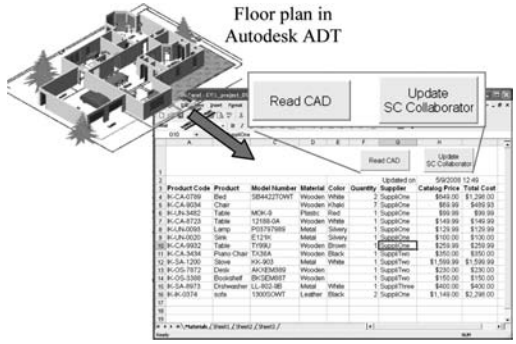

Figure 6. Extracting item information from a floor plan in Autodesk ADT to a spreadsheet in Microsoft Excel.

4.3.1 *Procurement interactions*

E-Procurement has gained huge popularity as many studies have shown its values in supply chain management. Beyond the obvious transaction cost savings and access to suppliers, e-Procurement can offer product standardization, quality assurance, inventory management and the opportunity to manage material flows down the value chain (Issa et al. 2003). As reported by Sanders (2001), the benefits of e-Procurement can be tremendous in terms of savings in cost and time, return on investment, and improvement in customer relationship. This example demonstrates the e-Procurement activities performed using SC Collaborator.

For most e-Procurement systems, it usually takes time to configure and establish the communication channels between buyers and suppliers. On the contrary, the communication channels can be easily and quickly created and removed in SC Collaborator due to its service oriented architecture. To establish a channel, the organizations simply need to create an account in SC Collaborator for their trading partners, and exchange the IP address with each other. This facilitates the addition, replacement and removal of trading partners, which happen frequently in fast changing AEC supply chains.

In this example scenario, an interior designer working with a general contractor company *Gen-Con* extracts the items (such as furniture items) and associated information from Autodesk Architectural Desktop (ADT) to Microsoft Excel (Fig. 6). The procurement list is submitted to the SC Collaborator system for review. The procurement officer in Gen-Con can log on SC Collaborator and evaluate the items proposed by the architects. As illustrated in Figure 7, the system stores and keeps track of all the product and status information for each item. By selecting the items and providing the order number ("OH-whx-90"

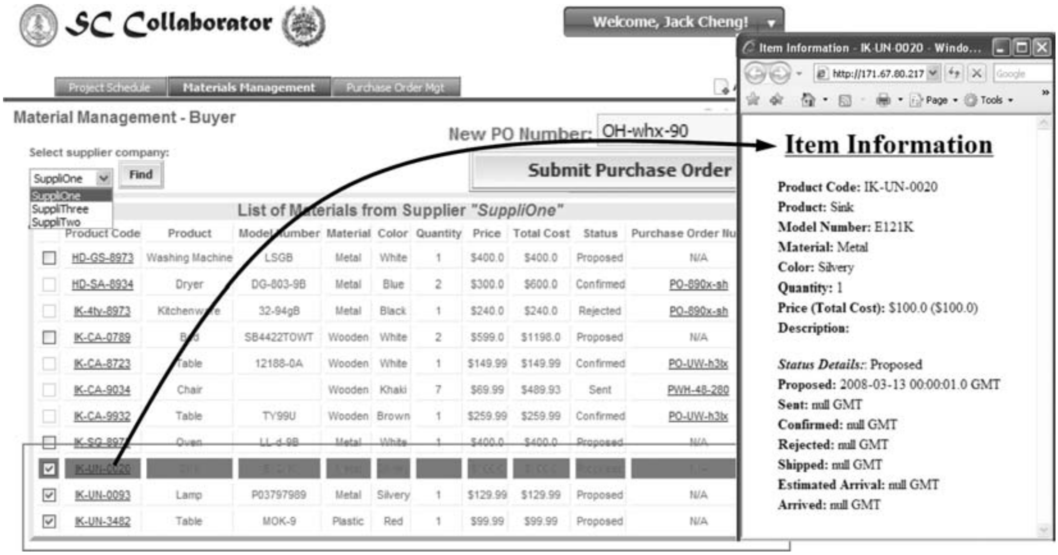

Figure 7. Review of procurement item list and submission of electronic purchase order by GenCon.

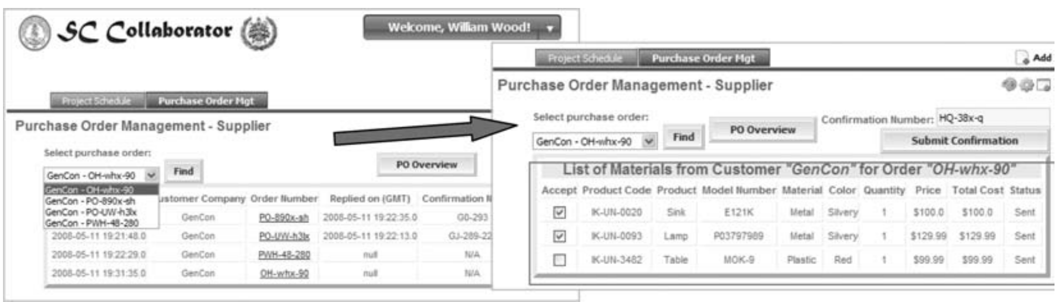

Figure 8. Managing purchase order in SC Collaborator by SuppliOne.

in this case), electronic purchase order can be easily created and sent to the designated suppliers through web services.

The supplier *SuppliOne* logs on its own SC Collaborator system and manages the purchase orders it receives (Fig. 8). The purchase order submitted by GenCon is received in SuppliOne's system instantaneously. After considering its inventory information, SuppliOne decides to offer only two of the requested items and responds to GenCon electronically with a confirmation number. Figure 9 shows the updated information in GenCon's system right after SuppliOne's responses.

4.3.2 *Material delivery management*

The second example illustrated in Figure 10 demonstrates the online collaboration and information flow among a general contractor, subcontractors and suppliers using SC Collaborator to manage material delivery. In this example, one of the suppliers of the mechanical, electrical and plumbing (MEP) subcontractor has to delay the material delivery of two items. As shown in Figure 10, the delay notice sent by the suppliers triggers a message in SC Collaborator delivered to both the general contractor and the MEP subcontractor.

The general contractor provides the MEP subcontractor with two options – to change the supplier so that the schedule remains unchanged, or to request a task delay with a penalty. The subcontractor uses SC Collaborator to connect to the systems of the suppliers with partnership agreements, and checks the available alternative suppliers for the two items. The subcontractor finds that one of the items is out of stock among the partner suppliers, which means that a task delay is unavoidable. The subcontractor then makes a schedule

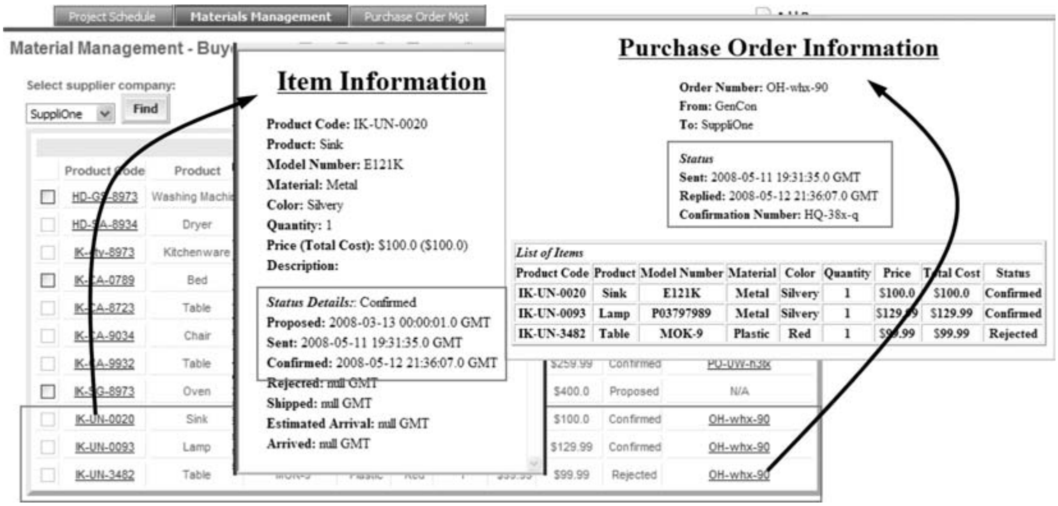

Figure 9. Updated item status and purchase order information in GenCon's SC Collaborator system.

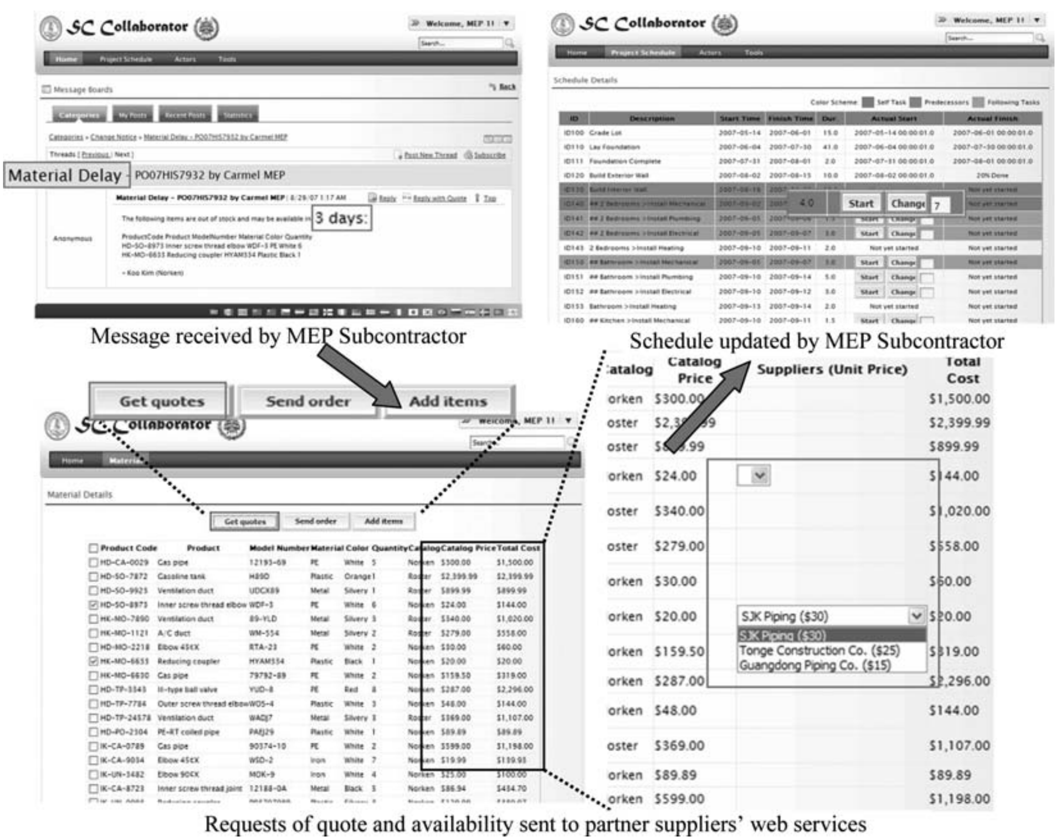

Figure 10. Material delivery management scenario using SC Collaborator.

delay for the affected task in SC Collaborator, as illustrated in Figure 10. All the project participants obtain an updated schedule instantly to plan and revise their tasks.

5 SUMMARY AND CONCLUSION

The lack of interoperability can seriously hinder project coordination and collaboration, which are vital to the success of a supply chain. It has been reported that insufficient interoperability causes huge economic costs to various industries. Therefore, significant values can be added if interoperability is facilitated among supply chain members. Software interoperability which supports the integration of information, software applications and engineering services has been discussed. With the proliferation of Internet, the web services model has emerged as a promising approach to application, process and information integration. With the service oriented architecture, the web services model enables modular system development, reusability of web service components and high re-configurability. Therefore, the web services model can provide a useful framework to facilitate collaboration and interoperation for the fast-changing construction supply chains. Specifically, web portal technologies which implement the web services model are leveraged to provide the users a unified point of access. A distributed portal network architecture is proposed to extend the web portal framework and to promote sharing of sensitive and proprietary information.

In this paper, we present SC Collaborator, a prototype web-based portal platform designed to facilitate information sharing and interoperation within and across organizational boundary. The platform implements the distributed network architecture using standardized web services languages and protocols. The platform leverages open source software tools to provide an economical solution for AEC companies, which are mostly small to medium in size and reluctant to invest heavily on IT. Two illustrative examples are provided to demonstrate the interoperation among stakeholders using SC Collaborator for procurement and material delivery in AEC projects.

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Model-based eServices for supporting cooperative practices in AEC

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ABSTRACT: The design of IT-services to support cooperative activities in AEC has been largely addressed in the "IT for Construction" research community. Nowadays numerous research efforts focus on BIM and its capability to change the cooperation work practices in the future. Our approach, in cooperation with Luxembourguish practitioners, targets the today practices and the professional needs related to IT-support to cooperate. Of course numerous commercial softwares are distributed on the market, but they are often under-used because of their multiplicity and their inherent complexity of use. They are also not enough interoperable between them and above all they are not integrated with internal systems that many organizations have setup. The CRTI-weB services presented in this paper try to target precisely the AEC business requirements through a design stage based on cooperative professional practices identification. The service-based implementation lets us also to envisage new ways of use: in some cases classical software tools could be replaced by eservices plugged into existing internal systems. We describe especially here the document management eservices that we have developed and which are experimented in real project cases.

1 INTRODUCTION

Cooperation between actors involved in AEC projects is an essential stake nowadays. Indeed many dysfunctions in construction projects are closely related to time, quality, human resources or cost management from a collective point of view. We suggest here to address the issue of cooperation in AEC projects through the potential of the use of CSCW[1] IT-services.

Previous research works identify the coordination as one of the major aspect of cooperation. Addressing coordination support through IT in AEC implies to take into account the specificities of the activity in this field. Its main characteristics are heterogeneous actors, short-term lived teams, unpredictable activities, "prototype" character of building projects etc.

In this specific context coordination is essentially the fact of the coordinator know-how. Even though in some countries coordination missions have been defined we think that regulatory approaches are not sufficient to cover the human, methodological and technological aspects related to this activity.

Through a computer support point of view we notice that:

- Tools are often "single business" oriented. It means that they are designed to support the specific activities of a single building trade and do not really support AEC activities in their cooperative dimensions.
- These tools present a lack of interoperability. Problems coming from exchanges of graphical representations of the building have been largely addressed by research and industry. We underline more specifically here the issue of interoperability between information systems (Nitithamyong & Skibniewski 2004) used in the organizations involved in a project and the capacity to consolidate heterogeneous data related to cooperation.
- Finally these tools, when they support management tasks (e.g. planning tools), only offer partial representations of the cooperation context to their users. Moreover, these representations are often related to

[1] Computer Supported Collaborative Work.

the classical information described in coordination documents (planning, meeting report, documents up-to-date lists…).

In this specific context our objective focuses on the design and appropriation of new IT tools to support cooperation activities in AEC. Cooperative tools used in other fields of activities have shown their limits when they have been applied to the building construction sector. It is due notably to their complexity and their irrelevance to the specificities identified above. Our basic hypothesis is that new tools supporting cooperation have to take into account these specificities. They also have to be able to be interfaced with existing tools in order to favor their appropriation and their use by the actors. A shared model of the cooperative activity is a way to integrate the different points of views existing in architectural projects. It should be also a way to achieve interoperability between heterogeneous and single-business specific tools.

Beyond computers and tools, the work practices themselves are often not aligned with a cooperative approach of collective work. For example, the tasks are very fragmented and actors generally act sequentially. We know that work processes in AEC are unpredictable and hard to manage. But very often, the actors do not take into account the work of the others following their own task, and we can notice that it is difficult to manage interfaces between stakeholders. Thus, we suggest that a human-centered dimension and the development of collective best practices of working are necessary to favor the introduction of new tools in the AEC sector.

The approach highlighted in this paper addressed both these technical and human-centered dimensions. The case study, which will guide us from theoretical propositions to practice implementation, is the issue of document exchanges management in AEC projects.

We will describe firstly the proposition of a meta-model representing the cooperative activity through the concepts of Activity, Actor, Document and Object and their relationships.

Then, we will identify the cooperative best practices that practitioners from Luxembourg have underlined. We will describe especially the results of a Working Group and interviews on the topic of the improvement of document exchanges practices.

The main result of this work is the development of a platform of e-services supporting cooperative practices and adapted to the specificities of the building construction practices. These e-services are described and designed according to the semantics of the Cooperation Context Meta-Model (CCMM).

We will present a Web-based document management tool based on a part of our e-services related to document exchanges. This tool is under experiment for the moment and we will present the first results of this experiment in real project cases.

Finally, we will describe our prospects related:

- To the document management IT-support issue,
- And to the modeling of services in a dynamic of reuse and project adaptability.

2 A MODEL-DRIVEN APPROACH FOR THE DESIGN OF COOPERATION E-SERVICES

2.1 *State of the art*

Nowadays, project platforms become more and more used, especially in large construction projects. Important issues targeted by research are related to the interoperability between the heterogeneous platforms (Moses et al. 2008) and to the integration of eservices in a business-oriented way (Katranuschkov et al. 2001). Designing cooperative services relates to market-based requirements and faces technical and infrastructural constraints. Beyond the technical integration of services, we identify that there is a need of a semantic framework enabling the definition of services targeting identified business fields.

Moreover, the classical CSCW services used in other industries show their limits when they are applied in the AEC activities. In our domain projects are highly collaborative, non-repeatable and composed of heterogeneous actors. The situations of IT services deployment have to fit the situations of use, always specific to each project: involved users, project organization, contracts or IT infrastructure.

2.2 *Modeling the cooperation context*

We use the Model-Driven Engineering (MDE) methodological framework (Bézivin 2005; Favre 2004) and propose two levels of modeling for the cooperative activity in the AEC domain. Firstly, a meta-model of the cooperation context allows us to describe the cooperative activity at a high level of abstraction. This meta-model is used to define a specific model representing the particular context in an operation of construction. MOF architecture, which we base this reasoning on, integrates perfectly in the approach with models and meta-models of MDE. This particular work is more precisely described in (Kubicki et al. 2006).

Our relational cooperation meta-model takes into account the existing relations between the elements of a project. We identify four main elements existing in every cooperation project: activity, actor, artefact and tool.

Then, a model – focusing on the specific building construction activity – has been developed. It represents the specific context of construction: realization tasks, involved actors (i.e. firms and facilities), tools used (i.e. planning tools) or documents (i.e. meeting report). For example, it allows us to manage explicitly the relationships existing between two documents: a remark in the meeting report concerns a task in the construction planning.

2.3 *Modeling the views*

The development of new interfaces to be integrated into cooperation assistance tools has to take into account the existence and the specificity of "business-views". These "views" of the cooperation context are those that professionals manipulate in their daily work.

So, we propose to model the "views" such as they are used in the tools supporting cooperation, which are existing and/or emergent. We precise that the model of visualized concepts defines only the semantic content of a view, turning down technical dimensions, model of navigation, model of tasks and other specific models for HCI (Ian Bull & Favre 2005). Then, a view can be represented with three abstraction levels like the levels of modeling of the cooperation context. At the bottom, we find the view itself, i.e. the user interface operated in a tool (e.g. a view of the execution planning).

Thus, its model represents the concepts that the interface uses. These concepts are specific for the profession that uses the view. In our example, the view planning represents the "resources" (firms), the tasks, their temporal links, and it is a view generally used by the coordinator.

2.4 *Model-driven service design*

Until now, this model-driven framework especially led us to define two coordination-specific views:

- Bat'iViews: a multi-views interface enabling contextual navigation in AEC-traditional views (Kubicki et al. 2007).
- Bat'iTrust: a dashboard view based on the concept of trust in the good progression of the construction activity (Guerriero et al. 2008).

In these works the objective were to suggest new visualization modes based on a credible source of information. However everyone knows that information is scattered among multiple sources, especially in the AEC domain where:

- Numerous documents are produced and used. There is a risk of redundancy and incoherence between them.
- Information sources are not centralized, they are often hosted internally by the actors producing it.

Then the suggested modeling framework enables a theoretical definition of the cooperation context and led us perform prospective research works on this basis.

However, the applied research that we carry out in the framework of the Build-IT project at the CRP Henri Tudor is oriented towards the specification and implementation of cooperative services for the building construction sector in Luxembourg. In this context the theoretical research about domain modeling (AEC cooperation context) has become the basis of our developments. The model of the cooperation context (§2.2) has been enlarged in order to fit the needs of our applied developments. It is the basic information model allowing us to describe the AEC-specific concepts manipulated by the users through the "CRTI-weB services".

3 IDENTIFICATION OF BEST PRACTICES RELATED TO DOCUMENT EXCHANGES

3.1 *Methodology*

At the origin it was decided to address the issue of document management through two viewpoints: the human one (and its social dimension) and the technological one (i.e. existing software solutions).

Similar research works have shown the importance of metadata structuring (Caldas & Soibelman 2003; Forcada et al. 2007) both through the human viewpoint (Why do I share a document? How documenting a document flow?) and the technological/modeling one (How describing metadata? How should the users fill in metadata?). Turk & Björk suggested notably a model describing document-related concepts: presentation, document life-cycle, organization and link with building product model (Turk & Bjork 1994).

In this context, designing a document management system for the AEC sector is not really innovative. Facing the demand of the CRTI-B[2], we have defined an original approach of "open-innovation" where:

- Requirements of the system have been formulated by the end-users themselves through an enquiry/interview stage,
- Specifications have been regularly validated by practitioners.

Our enquiries showed that most of the users were not really satisfied with the existing solutions. Some reasons were collected through brainstorming with practitioners. Interesting synthesis papers also introduced some metrics and indicators to understand the factors of success or failure of AEC groupware solutions (Nitithamyong & Skibniewski 2004; Nitithamyong &

[2] The CRTI-B (Resource Centre of Technology and Innovation for the Building sector) is a luxembourguish organization involving the main representative actors of the construction market (both public and private). It funds national R&D projects targeting short-term innovations such as the development of services supporting cooperation and favoring the efficiency of construction projects.

Skibniewski 2007). The complexity of their functionalities is one important reason (Björk 2002).

We think that most of the barriers expressed by users and/or found in literature should be overcome if we approach them through a professional practices viewpoint instead of a computer-supported viewpoint. The following section (§3.2) describes the basic cooperation practices agreed *mutually* with the practitioners.

Our first aim in defining best practices related to document exchanges is to sensitize the AEC practitioners to the fact that every Electronic Document Management system (EDM) should help to realize them. But beyond, the CRTI-B pushes a global standardization strategy in Luxembourg. This strategy targets the practices but also the tools. The set of IT services that we develop, called CRTI-weB, focuses on the support of cooperation best practices. The R&D development cycle that we have setup covers the steps of specification, design, experiment and goes towards the transfer of the tools and practices to the AEC national market.

3.2 *Best practices related to document exchange*

The best practices related to document exchange processes have been identified with the practitioners and have been agreed by the CRTI-B working group. During the preliminary enquiry stage we have discovered numerous internal document management methods. Our work consisted then to extract the high-level practices, i.e. the common denominator, on which everyone could agree.

The resulting best practices are described below, in simple terms. They should be applied in specific project setup situations, in totality or not:

1. A common structuring of project documents is defined (P1).
2. A standard naming of project documents is setup and agreed by all the actors involved (P2). In Luxembourg the OAI[3] has developed a standard name norm, which is notably used in public buildings projects.
3. Modifications are described and localized on new releases (P3).
4. When a document is shared, it is necessary to inform the interested participants of its availability (P4), i.e. a document is always shared for a good reason.
5. Requests between project's participants have to be recorded in order to manage it (P5).
6. Interactions and reactions about a document between participants have to be recorded (P6).
7. Defining privacy areas for document sharing (P7).

[3] OAI is the Order of Architects and Consulting Engineers from Luxembourg. http://www.oai.lu

These practices appear simple and common. However defining and applying them in project situations is not so easy. Very often a coordinator should be in charge of verifying and sensitizing the participants to them. Of course, IT supports the realization of these cooperation practices (CSCW, groupware tools). But in numerous cases we observed that tools are too complex and not adapted to the AEC specific activities. Then the users are confronted to practical problems in their document exchanges and retrievals. They loose time and logically do not spent much effort to improve their practices.

This assessment lets us to propose a prototype tool implementing these basic best practices into simple IT services.

4 CRTI-weB [DOCUMENT MANAGEMENT] SERVICES

4.1 *Document management tool*

A first set of services has been developed previously to support meeting report writing and diffusion (Kubicki et al. 2006). We present here the services dedicated to document exchange management, supporting the practices described before.

4.1.1 *Services presentation*

In order to support the basic cooperation practices of document exchange the following services have been developed.

A *file name management service* enables the use of a standard for naming the documents. It is defined for each projects and enables to obtain the metadata of a document when it is uploaded (P2). Standard name is composed of fields and separators. The service parses the name of the document submitted and interprets its content. If the user uses standard names for his documents, he has just to check if the name is correct and to validate. If not, he can re-name his file using the field contents that the tool suggests him.

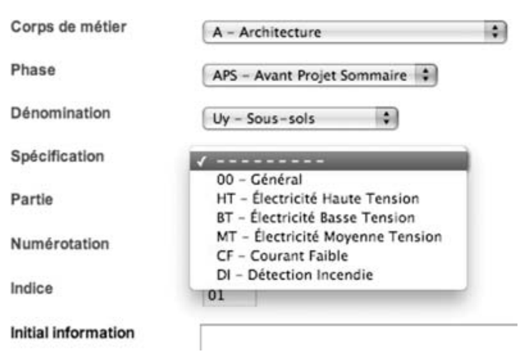


Figure 1. The auto-filled field of the naming standard.

The use of the fields “phase” (project stage) and “indice” (release number) are required. They enable to structure the documents by stage (P1), and to follow the releases (P3).

A *request service* has been developed to manage and keep trace of the interactions between the users about a document (P5).

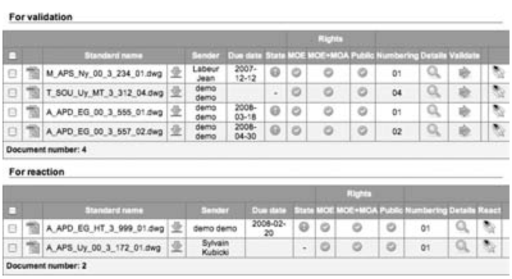
The author of a document can inform someone else that a document has been uploaded, request a validation or ask for a reaction.

The *reaction service* traces the discussion between users about a document (P4, P6).

A *notification service* allow the users to receive notification when a document is uploaded, updated or when various actions are performed (such as leaving a reaction, assigning a request and so on).

Finally, a *privacy management service* enables to setup privacy areas in which the users should access or not (depending on their rights)(P7). We have defined 3 areas: 1) “architect + engineers” area (MOE), 2) MOE area extended to the owner and 3) a public area (e.g. comprising the contractors).

Figure 2. Hierarchy by stages obtained for the “stage” field.



For validation

		Standard name		Sender	Due date	State	MOE	MOE+MOA	Public	Numbering	Details	Validate	
		M_APS_Ny_00_3_234_01.dwg		Labeur Jean	2007-12-12					01			
		T_SOU_Uy_MT_3_312_04.dwg		demo demo		-				04			
		A_APD_EG_00_3_555_01.dwg		demo demo	2008-03-18					01			
		A_APD_EG_00_3_557_02.dwg		demo demo	2008-04-30					02			

Document number: 4

For reaction

		Standard name		Sender	Due date	State	MOE	MOE+MOA	Public	Numbering	Details	React
		A_APD_EG_HT_3_999_01.dwg		demo demo	2008-02-20					01		
		A_APS_Uy_00_3_172_01.dwg		Sylvain Kubicki		-				01		

Document number: 2

Figure 3. View of the actions of a user about documents.

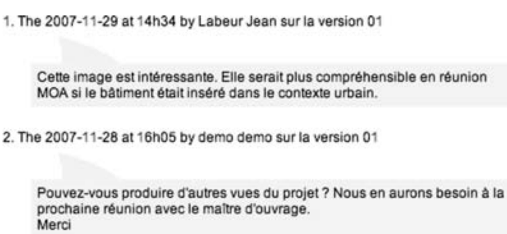


Figure 4. A view of a list of reactions about a document.

4.1.2 *Architecture*

Originally our developments are based on a classical PhP/MySQL client/server infrastructure enabling the description, storage and retrieval of cooperation context data in a database. Inspired from other approaches, such as the one developed in the ISTforCE EU project (Katranuschkov et al. 2001), we oriented our developments towards a service architecture. Our eServices platform manages the cooperation context (based on a specific construction domain model instantiated from the CCMM).

The business-oriented services described above have been developed through the use of Web services, facilitating the integration in existing infrastructures. These Web services are described in the REST protocol (Fielding 2000) and should also be available in SOAP. REST is a Web services technology based on the Web architecture and its basic technologies: HTTP, URI and XML. We structured these Web services using the ROA approach (Resource Oriented Architecture)(Richardson & Ruby 2007). It describes a set of good practices for REST Web service design and is very adapted to our Agile development process, involving business experts, technical experts and final users in the design process.

4.1.3 *Experiment*

The services are implemented in a Web tool[4]. A first experiment has been carried out in a pedagogical environment during 3 months (between architect students from Nancy and Liège[5]). It allowed us to validate the functionalities of the tool. We underlined also with the students the importance of setting up a cooperation context in which human practices take place. The tool comes after this necessary stage, providing a support to mutually agreed practices. The students also had many new ideas to improve the tool, such as adding forum or chat services, or developing a document preview service.

Experiments in real construction projects have begun since April in Luxembourg. At this time, the tool is used in two small/medium size projects. We expect to enlarge the scope of project sizes and of team organizations. Until now, we noticed the essential stage of setting up the tool. It is indeed closely linked to the definition of the cooperation practices for a specific project context.

[4] Demonstration available at http://demoged.buildit.tudor.lu (login: “demo”, password: “demo”)

[5] For more details see: http://www.crai.archi.fr/SDC

For example, in a very small project the users do not define a standard name to exchange the documents. In this case we try to setup the tool in order to simplify the naming of documents (i.e. less metadata is required), but we see here some limits related to our tool designed to support standardized practices.

This remark opens very interesting thoughts about how developing services that fit the particular characteristics of a specific AEC project.

4.2 *Perspectives*

The document management services presented in this article are implemented in a tool which is still in experiment stage. This section describes the perspectives we have for the future developments on this issue.

4.2.1 *About document exchange support*

This approach of documents sharing in projects is reinforced by the issue of internal management of documents. During our specification stage we underlined the problems related to management of documents inside the organizations and we noticed the various levels of maturity of these practices. Then we tried to identify the related best practices, such as managing documents on a file server, uploading/downloading documents from a project platform, storing modifications lists on document releases, managing internal requests between project team members and so on. We have also specified the support services which could help to improve these practices and we are now developing a prototype of an "internal client" tool implementing it. Through this development we aim both 1) to improve internal practices and 2) to foster the use of the cooperative project platform CRTI-weB through document synchronization mechanisms and simplified forms.

The document exchange issue is the second research axis of the Build-IT project. This project addresses specific development of cooperation support services and also aims to accompany the Luxembourguish construction sector towards electronic cooperation and in the future, towards Building Information Modeling. In this context we introduce progressively the link between today's tools and future tools based on digital modeling of building (BIM). Then, in the documents management prototype, we introduced this link through references to building elements. For example when a user describes a modification made on a document, he is required to fill in the "localization" field. For us, this is a first step towards the integration of document oriented systems and product oriented systems (Rezgui & Cooper 1998), aiming to sensitize the users to the need of better documenting the exchanges, and to the upcoming benefits of BIM.

A third important perspective is related to the transfer of project content from an EDM to another. In fact, many project collaboration solutions exist on the market. Everyone agrees to say that one major limit of the appropriation of such tools by the end-users is that they often have to use (and to adapt to) one tool for one project. Moreover there is a real problem of project data archiving (Moses et al. 2008), especially when data is stored by an external

Figure 5. CRTI-weB [Document Management] Tool – Main interface.

provider. We envisage to address this issue through our model-driven approach by specifying model transformations based on the AEC-specific cooperation model (§2.2).

4.2.2 *About service modeling*

The experiments (§4.1.3) show the importance to adapt the service offer to the specificities of each project situation. There is a close link between project specificities (in terms of actors organization, administrative stages, constructive solution...) and services used. This question has been addressed in other fields, as the "IT-business alignment" problem. We envisage to address this alignment through two related issues: the modeling of IT service and the collaborative design of services.

The first one aims to integrate three dimensions of service modeling: the functional aspect (what service does in business terms), the non-functional aspect (quality of service, Service Level Agreements) and the transactional aspect (how services are composed together in processes). Modeling these three aspects of service is the most generic way to describe them and to enable their composition. We also target the integration of heterogeneous services e.g. the ones that internal organizations should developed for themselves firstly and distribute in project teams after.

The second issue addresses collaborative service design for specific projects situations through the integration of multiple expert viewpoints: the business requirements viewpoint (i.e. what are the project practices?), the business solution viewpoint (i.e. how services can support these practices?) and the technical solution viewpoint (i.e. is the service compatible with a particular infrastructure?). A collaborative service design approach is characterized by numerous experts bringing their own viewpoint. Service modeling has to describe these viewpoints in order to enable their re-use at different levels. In other terms, a service described in a business-oriented language could interest domain specialists for specific AEC project situation. Then technical-experts have to control that such a service is adapted to the technical infrastructure used. The reverse is also important: it could allow IT-experts to analyze IT services capabilities in order to suggest it at the business requirements level (e.g. when business experts are defining the working practices).

Modeling the IT-services will be realized in relationship with our cooperation context modeling infrastructure. It will allow us to realize concepts mapping between domain-specific models and service models in order to describe functional and non-functional aspects based on a domain-particular semantic. Moreover it lets us envisage to link the service composition description to specific domain processes instantiated from our meta-model.

5 CONCLUSION

In this paper we describe our activities of design of cooperation support IT services. Especially we present document management services and their close relationships with identified professional cooperative practices.

The modeling approach characterizing our parallel research works in contextual visualization is applied in service design, and allows us to design services adapted to the specificities of the building construction domain. It opens prospects towards the collaborative design of services and their composition in order to fit the specificities of each AEC project.

We also described our issues related to appropriation of such services. The service approach itself differs from "classical integrated tools" solutions. It favors technical interoperability between systems and lets us envisage for example to provide the independent services in existing EDM systems. Beyond we also envisage the sharing of services, enabling for example one firm to design internal services and share it with a related community of interest.

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Development of an e-service for semantic interoperability of BIMs

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ABSTRACT: Focus of the paper is interoperability of heterogeneous information systems in construction where building information models, BIMs, are used. In the paper we introduce a methodology DRAGOn (Disharmony Resolving with Agents and ONtology) that uses a concept of virtual product model with belief that it is possible to preserve the independence and flexibility of proprietary BIMs while demonstrating a certain level of interoperability that results in decreasing semantical and structural difference between product models. The methodology includes definition of structural and semantical disharmony for information models in general and defines conceptualization for structural and semantical disharmony, a disharmony ontology. The disharmony ontology can be formally specified as an OWL ontology. Software agents can use the ontology to resolve structural and semantical conflicts between applications. The agents communicate via shared communication space, a middleware that enables mediation of semantically different BIMs. The mediation incrementally builds local ontologies. The ontologies are used as persistent repositories of concepts (structure and semantics) that are captured from applications during run-time. Extensive applicability of the methodology is expected in construction industry with rich, complex and dispersed data content.

1 INTRODUCTION

Today's best information modelling practices in engineering show a tendency to build a unique all-inclusive product information model for a specific engineering field (like shipbuilding, car industry, building industry, road building, etc.). However, none of these attempts has been generally accepted in the civil engineering practice. Rather than that, the past development of building information models (building product model) led to a question, whether a definition and use of a standard product model has sense at all. To overcome the need to have a single product model some authors have proposed inter-model linking schemes (like in Hardwick 1997 and Pfennigschmidt et al. 1997), in this way, however, the complexity of the whole system hasn't decreased, even worse, it has grown.

Another problem arises from the necessity for standard building elements. The history of mankind shows that in communication the only "standard" is the diversity of standards. In other words, it seems most unlikely that the whole of mankind would use a single standard language. Even if such a language would exist, it is very likely that soon many dialects would appear, since every individual or group is seeing the same thing in its own perspective.

This problem is also present in civil engineering and construction, where many different views have to be considered through a building life cycle. Different views are leading to more or less different descriptions (data structures) representing the same entity. Notable progress has been made by the International Alliance for Interoperability (IAIa 2008) with the development of the common specification for information model (IAI IFC 2x3) rooted in the Industrial Foundation Classes (IFC), which can be seen as applicable building blocks tailored to cover the software interoperability within the AEC industry. IAI has made it to become an ISO "Publicly Available Specification" (IAIb 2008).

STEP technology (STEP 2008) has succeeded as an ISO 10303 standard. It was supposed to be much broader in scope than IFC and with the ambition to seamlessly integrate processes in manufacturing engineering. The ISO 10303 standard bundle contains over 100 published technical specifications. But will they prevail over IFC or vice versa?

A conflict between the concept of a single project integrated model and the need for individuality also showed up. Companies (and individuals) have a strong inclination to fully control their own data, which also form the company's "memory", a vital part of every company.

The main deficiencies of product information models could be summed up into the following essential points (Tibaut & Rebolj 2003):

Product models are based on clearly defined semantics and demand unique standard basic elements, however, such elements don't exist, computers are not (yet) capable to fill up semantic inconsistencies and gaps, which show up in the integration of computer programs – a human is adapting daily to communication patterns with other humans with different mental models, and is capable to reconceptualize parts of information, which don't fit into the whole,

- product models are subjective interpretations, not objective representations of the real, therefore an effective uniform product definition is not possible,
- product models only include parts from the building process and disregard some important views (social, environmental, etc.), which form the process in reality,
- models are restricting creativity due to their complexity and rigidity,
- when implementing prototype models into the real environment they fail due to the inability to capture the rich knowledge and experience of the people,
- although product models are basically open, they get stiff and hardly upgradeable in reality,
- in an integrated database each client's control over his own data is limited.
- Years ago construction IT scientists (Eastman & Augenbroe 1998) and (Turk 1999) already proposed some solutions to the problems they described:
- product models should be rather small and limited to specific areas; coexistence of more models in the same field is not necessarily bad,
- implementation of middleware tools between applications and models, which will help humans to navigate between the islands of automation,
- gradual implementation of small models into industry,
- development of a richer set of language constructs for model description,
- product and process models should be linked more closely,
- new integration concepts should be developed, which would not reside on integrated semantics,
- it is necessary to allow coexistence of structured information and unstructured data and leave their interpretation to the human,
- pure information exchange should be upgraded with communication software for collaboration support.

Furthermore, authors (Boddy et al. 2007) conclude that in the last 20 years computer integrated construction research produced software solutions focused on data and application integration that in consequence lead to tightly coupled information systems and complex building information models. The latter, complexity of handling a shared building information model, is also confirmed through research case studies (Plume & Mitchell 2007).

We can conclude that the applicability of "giant" information models is limited because of their complexity and lack of adaptability. As such they require too many agreements and change from diverse users. In the future we won't see any prevailing international standard for product modelling but number of best-practice examples commonly used at different levels (company-wide, country-wide, maybe even continent-wide) that will require collaboration with each other.

In such a world only those information model concepts that feature some degree of self-initiative and adaptability will be widely accepted. Any other concept risks the high migration cost to be paid by its users.

2 FORMALIZATION OF DISHARMONY IN PROPRIETARY BIMS

Our research tries to diminish disharmony effects within heterogeneous federated software systems (HFSS) where set of complementary applications that contribute to a global goal wouldn't need to abandon their local data views. A natural assumption is that applications are autonomous in modelling and managing of structure and semantics of their data.

We define heterogeneity as an intrinsic property of an information system. Disharmony of an information system is defined as a state of the system that changes over time and we are interested in conflicts that arise from that. Further, structural, semantical and functional disharmony is defined as part of overall information system's disharmony.

Two different disharmonies can be defined:

- Static disharmony is a conflict state within a set of collaborative software systems "before its first run"; at least two applications within HFSS cause heterogeneity
- Dynamic disharmony is a conflict state within a set of collaborative software systems "during the run"; a new application that cause heterogeneity is added to an existing HFSS

A good example of disharmony problem demonstrates a HFSS with discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle. To facilitate full interoperability between the applications state-of-the-art scenario would be to use standard schema (i.e. IFC) with import/export mechanism between the internal data models of specific building modelling applications, such as ArchiCAD and Autodesk Revit for example, and server based building information model. Therefore the standard schema must define building entities that represent union of all the entities (i.e. window, wall, column, etc.) found in internal data models. Such a schema doesn't exist. Therefore disharmony problems can not be avoided in real construction projects.

2.1 *Structural disharmony*

Structural disharmony occurs when one application requests data from another application:

– Structural disharmony is a conflict state between two applications in a HFSS because of differences in data format structure and data names

Structural disharmony can have different forms:

– different structure for the same concept
– equal structure for the same concept but with different names
– equal name for different concepts

2.2 *Semantical disharmony*

Semantical disharmony (example: Picture 1) occurs when one application receives data from another application, but interprets its meaning wrong or fails to interpret it at all:

– Semantical disharmony is a state between two applications in a HFSS because of differences in meaning of data (semantics) with equal or related structure that represent the same concept

Examples for semantical disharmony are:

– semantically equivalent data with different precision
– semantically equivalent data represented with different units

Resolving disharmony problems between building information models means resolving structural and semantical disharmony.

Structure and semantics can be further defined as *implicit* or *explicit:*

– Structure or schema for data is implicit if its description is not separated from data.
– Structure or schema for data is explicit if its description is separated from data.

BIMs with implicit structure are exclusively managed by a software program released by a given organization. With the proprietary approach, the security is higher and reverse-engineering a proprietary algorithm is difficult, but this is compromising software collaboration within construction project. Explicit structure or schema (data in a file follows a hierarchy, grouping, example is XML with XSD) approach is well suited for machine interpretation.

Equivalently we can define *implicit* or *explicit semantic*:

– Meaning or semantics of data is implicit if its description is not separated from data.

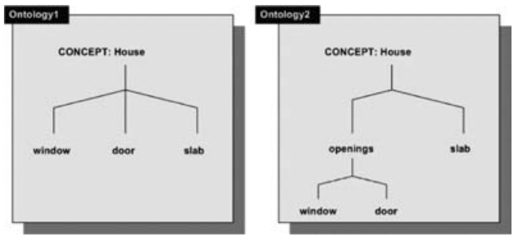

Figure 1. Semantical disharmony example.

Meaning or semantics of data is explicit if its description is separated from data.

Existence of explicit structure and semantics for a BIM enables the BIM to be readable and understandable by software applications. However this is yet unreachable goal for HFSS in construction practice.

A methodology that we propose for resolving structural and semantical disharmony in HFSS applies only to BIMs with explicit structure and semantics respectively.

2.3 *Classification of data models in relation to structure and semantic*

To formalize the notion of structural and semantical disharmony we need to identify a quality of description of structure and semantic for a given building information model. For the purpose we introduce a metrics that denotes the quality of structure and semantics, *QSS* (*Quality of Structure and Semantics*), for a given building information model.

$$QSS = Str_{\{i,e\}}, Sem_{\{i,e\}}$$

Str_i = implicit structure

Str_e = explicit structure

Sem_i = implicit semantics

Sem_e = explicit semantics

The value of *QSS* describes a HFSS's structure and semantics as four discrete states (Table 1).

The *QSS* has a real value if it can be determined for every building information model. How can we possibly explain that a picture has $QSS = (0,0)$? If not, than there should be an explicit schema that describes the order of pixels that compose the image, and explicit semantics description could be used by a pattern recognition algorithm that would realize, for example, that a construction site activities are behind the project schedule.

Table 1. QSS values

(Str_i, Sem_i)	(implicit structure, implicit semantics)
(Str_e, Sem_i)	(explicit structure, implicit semantics)
(Str_i, Sem_e)	(implicit structure, explicit semantics)
(Str_e, Sem_e)	(explicit structure, explicit semantics)

Another example is a VRML geometry model. A VRML model contains 3D geometry model together with animation path. 3D geometry is described with VRML entities like points, shapes, materials, interpolators, appearances, animation sensors, etc. The VRML model can be visualized with viewers, like CORTONA VRML client, that use proprietary (hard wired) algorithms for processing (implicit) structure and semantic. The VRML model has $QSS = (0,0)$.

The *QSS* value will be used as a trigger that determines how to approach disharmony resolving.

3 DRAGON – A METHODOLOGY FOR RESOLVING DISHARMONY BETWEEN PRODUCT MODELS

Based on the above formalization of disharmony in HFSS we propose a new methodology that dynamically resolves structural and semantical disharmony by preserving applications' local data model management. This is possible by understanding conceptualization for structural and semantical disharmony. a consequence a new methodology called DRAGOn (Disharmony Resolving with Agents and Ontology) uses conceptualization for structural and semantical disharmony, a disharmony ontology, and software agents technology. Disharmony ontology can be specified as an OWL ontology. Software agents can use the ontology to resolve structural and semantical conflicts between applications at runtime. Software agents communicate via shared communication space, a middleware that enables mediation of semantically different BIMs. The mediation incrementally builds local ontologies. The ontologies are used as persistent repositories of concepts (structure and semantics) that are captured from applications during run-time.

Extensive applicability of the DRAGOn methodology is expected in construction industry with rich, complex and dispersed data content. The general goal of DRAGOn is to help in discovery and decrease of semantic and structural difference between product models.

3.1 *Disharmony ontology*

We can now formally define a conceptualization for structural and semantical disharmony of data in HFSS. We will call it *disharmony ontology*. An ontology is specification of conceptualization. An ontology is a document that describes vocabulary for communication between humans and software agents.

Identification of concepts for the ontology is based on the knowledge (facts and rules) about data specification languages, like XML, ISO/STEP, IAI IFC and UML. Top level hierarchy concepts are: **concept Schema** (a meta description of a data structure), **concept Explicit Schema**, **concept Implicit schema**, **concept Schema about schema** (reference to schema components from a schema document, trend is towards using combinations of schemas rather than just one; XML technology enables use of multiple inheritance with schemas), **concept Schema language** (standard STEP uses EXPRESS schema language, while XML representation of schemas is XML in IFC), **concept Semantics**, **concept implicit semantics, concept Explicit semantics, concept Product Model**, **concept Building Information Model**, **concept Product model language** (language for product model description and schema language description can be the same), **concept Software tool for schema validation** (schema validators check syntax and structure conformance of schema with schema language rules), **concept Reference to schema** (product model can have an explicit reference to a schema which can be used for product model validation or product model can be validated against a software encoded schema), **concept Tools for product model manipulation** (a complete product model can be beneficial for different business cases that go beyond usual geometry exchange and visualization and involves also non-geometry applications like structural analysis, acoustic design, facility management, CNC machines; there are known cases of robotised laying of new asphalt layer), **concept Pool of supporting tools** (there are number of tools for conversion between different schemas, example is conversion of IFC SPF to IFC XML and vice versa, **concept Ego-centric technology** (a product modelling technology apparatus has a rather high gravity force for number of domains), **concept Technology implementation complexity** (a domain specific product modelling application authors are aware of the steep learning curve towards standard product modelling technology).

The conceptualization (hierarchy of concepts is shown on) is an input for definition of **disharmony ontology** in DAML-OIL, an ontology specification language. DAML-OIL is oriented towards web and is an upgrade to RDF and RDFS. RDF semantically upgrades XML. RDF/RDFS typically uses triples property, resource and value.

A complete disharmony ontology is located at http://www.tibaut.net/ontology/dragon.daml.

Part of the hierarchy of disharmony ontology is shown on Figure 2.

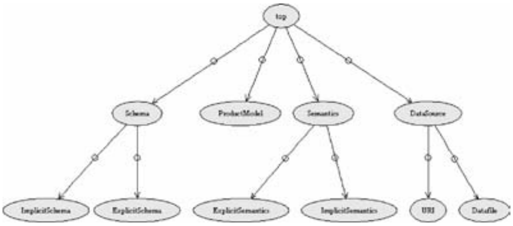

Figure 2. Disharmony ontology (partly): Hierarchy of concepts.

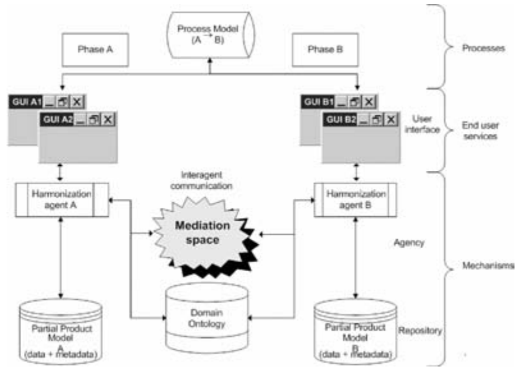

Figure 3. DRAGOn: supporting software architecture.

4 DRAGON ARCHITECTURE

In contrast to the traditional schema integration approach, more recent thinking is to "mediate" dissimilar data representations instead of "integrating" them. This mediation approach is typically done by using some mediation rules or specifications, which are used to resolve various kinds of conflicts among component systems at runtime. A mediated information system allows the users to see data in their own views. They can issue queries based on their own views and receive data in representations that are familiar to them. Furthermore, the mediation approach provides better support for system extensibility and scalability because, unlike schema integration approach, adding new component systems to the heterogeneous system can be done by changing or adding mediation rules or specifications instead of redesigning or modifying the integrated schema.

The virtual product model approach can be explained as a decomposed product model, consisting of the three main levels (Figure 3):

- mechanisms including repository with data structures used by applications and multiagent system which is responsible for structural and semantical harmonization of data in repository,
- end user services that include graphical user interfaces, and
- a process model, which determines the collaboration flow for applications (the "higher sense" of applications).

Our integration model can also be viewed as a multilevel integration model where the mechanisms implement the end user services that support the process. The process model encodes the set of goals and constraints of the context in which the end user services will be used to meet some objective of an organization.

It is believed that such federation of heterogeneous and decomposed data sources (product models A and B in Figure 3) will decrease complexity of the product model to a manageable level and increase it's flexibility through the autonomy of partial product models – components.

Some of the important features of our concept, motivated by the shortcomings of existing technology, include:

- the ability to share data across multiple heterogeneous data sources,
- the ability to manipulate the meta-data (schema) component of a data source in the same manner as data can be manipulated,
- increased adaptability towards foreign product models.

5 EXAMPLE

Figure 4 shows use of the DRAGOn methodology in the road lifecycle (the road has been in the focus of our research group for over a decade now (Rebolj et al. 2008). A simplified schema of the process model shows a chain of tasks, with the information about the program(s) and the external data representation used in a specific task. The process model is built, or adopted, for each specific project, because every project can include slightly different tasks, carried out by different programs.

The scenario starts with the activation of the task "Emission analysis", which is supported by the program named Dynem. When the user specifies the project name he wants to work on, Dynem tries to read relevant data. The read request is intercepted in an asynchronous way by the Dynem's harmonization agent through the mediation space that's created for the environment. The agent checks the status of the data in the project process model (implemented as a project database). If the requested data is harmonized with the predecessor components, the agent stores read request as a new tuple (tuple1, a set of objects) in the mediation space. Location of the data source is not determined

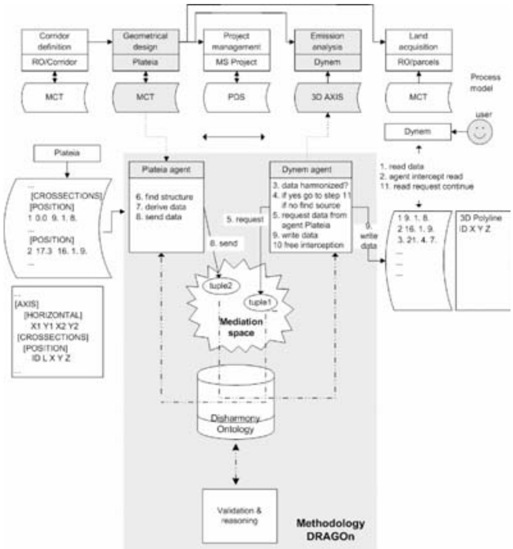

Figure 4. DRAGOn applied in a road design proces.

in the process model since it only access (reads, writes) the mediation space. The Plateia-agent, which is responsible for the geometrical design, detects the read request (tuple1) in the mediation space. When Plateia-agent gets the description of the requested data structure through the knowledge representation repository, it tries to find it in its partial product model and returns the data as a new tuple (tuple2) in the tuple space. Now the Dynem-agent detects the content he is looking for, reads the tuple (tuple2) and updates data in its partial product model. The user can then continue to work with harmonized data.

From this example it can be seen that data in the process is not harmonized all the time, but only on demand. This mechanism simplifies the harmonization of the model as a whole, but still assures correct data when it is needed.

It is believed that the DRAGOn methodology will be especially effective in civil engineering, where processes and partners, as well as applications used, are changing from project to project. However, same applications are used more often, which makes it possible for their agents to improve knowledge repositories.

6 CONCLUSIONS

In a real scenario domain specific BIM often uses different syntax and semantics than other partners' BIMs or "central" BIM. This leads to interpretation conflicts. For practical reasons (security, IPR) construction project partners want to retain their own project data view (as opposed to project data lock-in) using existing software architecture. Industry domain BIM standards, for example IAI IFC, are rapidly extending pool of supportive applications becoming. Still loss can happen both in importing from and exporting to the standard BIM. For the standard BIM to facilitate full interoperability between applications, it would have to be a superset of all their data models, which would be hardly realistic. Our methodology DRAGOn introduces approach that tries to understand disharmony problems in HFSS and decreases the semantical and structural differences in a construction project. Disharmony ontology helps to identify disharmony conflicts in data representations and software agents could help to resolve them. Such approach enables loosely coupled project software architecture as opposed to rigorous project discipline (to split a model to building levels). As a consequence this interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings.

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Integrating IFC product data services in distributed portal-based design environments

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ABSTRACT: The application of product data technology is a key factor for the achievement of efficient model-based collaboration in the construction industry. In practical terms, this means integration of a product model server into a web-based project environment, in tight relationship with traditional document management services offered by specialised Web Portals. However, at present portal based project support is almost fully disconnected from the offered product model services. This leads to gaps and disruptions in the information processing chain, inconsistency of the model data and, last but not least, lower and slower acceptance of the new model-based work paradigm. The goal of our research is to provide reusable, autonomous, web-based product data management services that are optimized for the IFC product model and that can be easily incorporated in a portal based IT environment, thereby closing the gap between model-based and document-based tasks and enabling harmonised treatment of the engineering collaboration processes. We suggest using the SOA technology (Erl 2004) for the integration of the full process model and the related services into an existing portal based design environment because of its capabilities for decomposing and recombining small functional units to complete business processes.

1 INTRODUCTION

The acceptance and application of product data technology (PDT) in the AEC/FM-industry has undoubtedly increased substantial within the last decade. The majority of the large CAD vendors (e.g., Autodesk, Nemetschek, Bentley) adopted the IFC standard (IAI 2006) and there are many people in the industry supporting the use of BIM as reflected in the corresponding trade magazines and Internet commentary sites (e.g., http://www.aecbytes.com, http://www.cadinfo.net). There is also a trend among prominent building clients (e.g., Audi AG, Lufthansa AG) to request comprehensive building information additional in the form of IFC product data as a condition of their contracts documents. In fact, this progress refers mainly to the strong effort of the IAI in raising the IFC standard from an idea to a mature product data model capturing the most domains involved in the life cycle of a construction project.

As a result the complexity and expressiveness of the IFC model increased rapidly documenting the strong heterogeneity of the different AEC/FM domains. Handling these highly complex, heterogeneous model data within long transactions without data locks exceeds to date basic model server functionality. Therefore additional product data management (PDM) services are needed in order to enable efficient use of PDT (Weise 2006). These services address the special needs of cooperative work within distributed virtual environments in AEC/FM industry and should warrant the consistency of the data during the collaboration process.

However, beside the development of model based systems and common standards in data representation enabling interoperability the progress of web-based project management and collaboration environments is commonly accepted as the other great trend in IT for AEC/FM. Whilst model based systems deal with fully structured data the major task of web-based collaboration systems is the management and exchange of unstructured or semi-structured documents according to the appropriate business processes and the specific roles and tasks of the project participants. Thereby the application of web-based collaboration systems is to date carried out as distributed portal based design environments almost fully disconnected from the offered PDM services. Design and construction processes, typically requiring both model and document information resources are treated separately, distorting the natural manner of cooperative design work. Given the fact that the model based project information becomes more and more complementary to the large amount of project information that is still represented and exchanged in form of unstructured documents this separation between the model-based technology and the web-based collaboration world contradicts the vision of an integrated information flow throughout the lifecycle of a project.

This paper outlines an approach to provide product data management functionality as reusable, autonomous web-based services within existing distributed portal-based design environments. The integration of the particular PDM services is carried out as flexible add-ons synchronized with existing project portal services and related project information resources based on the SOA technology. Thereby the conditional execution of the PDM services in a logical order constitutes the specific business process according to a generalized collaboration scenario.

2 PORTAL BASED DESIGN ENVIRONMENTS

Cooperative working in AEC/FM industry normally means a temporary coalition of numerous multidisciplinary and geographically separated organizations or persons related to a single construction project. In order to achieve successful completion of construction projects an efficient IT-based collaboration and communication support between the different project participants is needed. This support can be provided by the application of a construction project extranet (CPE). CPEs represent a special type of web-based collaboration technologies that are adjusted for the use in capital construction projects and hosted by Application Service Providers (ASP). This allows project participants to access the CPE directly through their Internet-browser with limited if any need for additional locally software. According to the CPE configuration the project information generated by the project team is saved to the CPE on the web for permission-based access by the other team members.

In general CPEs can be categorized in tools for

– Team communication and document management,
– Workflow and process automation and
– Process and project management (Becerik 2004).

Whereas recent CPEs often represent a user specific composition of this tools that are arranged around a comprehensive data repository during the design period of a construction project. The tools functionality is accomplished according to the business processes within a common project portal that is accessible through a standard Web-browser (Fig. 1). The following list shortly explains the current features of the CPE tools (that should be synchronized with the offered PDM services):

– Document management: This feature establishes a central location to store general project-related files, such as drawings, specifications, cost data, etc. It allows team members to manage, track and organize these files in a central location (including the possibility for up- and downloading documents). It allows also the use of meta data to specify the documents and their contents. Using meta data also enables linkage between documents, e.g. between drawings and material lists.
– Workflow management: This feature allows team members to collaborate electronically using requests of information, change orders, field notes, correspondence etc.
– Authentication and authorization: This feature structures the project team in a hierarchical order according to their functions defined by specific user roles. Each role determines the dimension of interactivity between the CPE and the role owner, the documents accessible by the role owner and the role owners integration into specific business processes (and respective work flows).
– Project directory: This feature stores general information of project team members in a central repository allowing easily retrieving of needed team information.
– Central logs and revision control (version management): This feature allows team members to track who accessed files or downloaded a particular document, as well as when the file was edited and uploaded to the system. It also includes the use of digital signatures to identify and verify an individual before entering the data or transmitting information (Nitithamyong 2004).
– Viewing and redlining: This feature allows the team members to get an optical impression of stored documents without downloading the file. Additionally some integrated document viewers allow the editing of stored documents e.g. for adding inspection or revision comments.

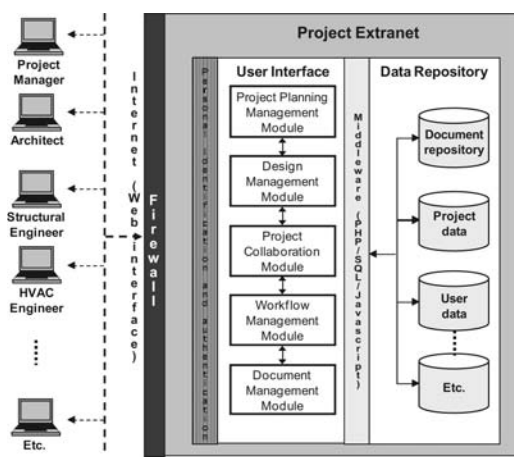

Figure 1. Functional scheme of a CPE (adapted from Nitithamyong, 2004).

Depending on the selected business model there may be some additional features provided by a CPE (e.g. conferencing and white-boarding, online threaded discussion, schedule and calendar).

A CPE is typically established within a client-server-architecture using the https protocol for communication allowing easy integration into existing security systems (e.g. firewalls).

3 PRODUCT DATA MANAGEMENT METHODS

Product data management encompasses various functions supporting model-based cooperative work in distributed design environments in order to maintain the consistency of the shared model data. These functions are structured in the context of a *generalized collaboration scenario* initially described in (Katranuschkov 2001) and further detailed in (Weise et al. 2004). The generalized collaboration scenario as well as the several PDM methods are shortly explained in the next sections.

Table 1. Examples of CPEs.

CPE service	Company	URL
EPLASS	SEIB ITC	www.eplass.de
conject	conject	www.conject .com
Citadon CW	Citadon	www.citadon.com
Active Project	Framework Technologies	www.activeproject.com
e-Builder	MP Interactive	www.e-builder.net

3.1 *Generalised collaboration scenario*

The *generalised collaboration scenario* considers collaboration as a repeatedly performed, well-defined concurrent process comprised of parallel engineering activities where model data are elaborated simultaneously by the different designers in the context of *long check-in/check-out transactions* and are then consistently merged together at a distinct coordination point, thus providing a consolidated new model state. The suggested generalised collaboration scenario includes a number of PDM methods that are largely independent of the specific design domains and tasks. These are: (1) *model view extraction* from the initial shared Building Information Model (BIM), (2) *normalisation* of locally changed model data, (3) *matching* the initial (checked-out) model data against the changed data, (4) *re-integration* of the changed data in the complete model, and (5) *reconciling and merging* the changed and eventually diverging models of the separate designers into a new consistent shared BIM (Weise 2006). Figure 2 shows the generalized collaboration scenario formed by the particular PDM methods between two successive coordination points.

3.2 *Product data management methods*

3.2.1 *Model view extraction*

The first method in the presented generalised collaboration scenario is Model View Extraction as a part of the check-out procedure. It provides functions for filtering the model data so that a meaningful model subset that is appropriate for the domain- and user-specific design task is created and stored locally for further processing by dedicated engineering applications. The created model subset is defined by a model

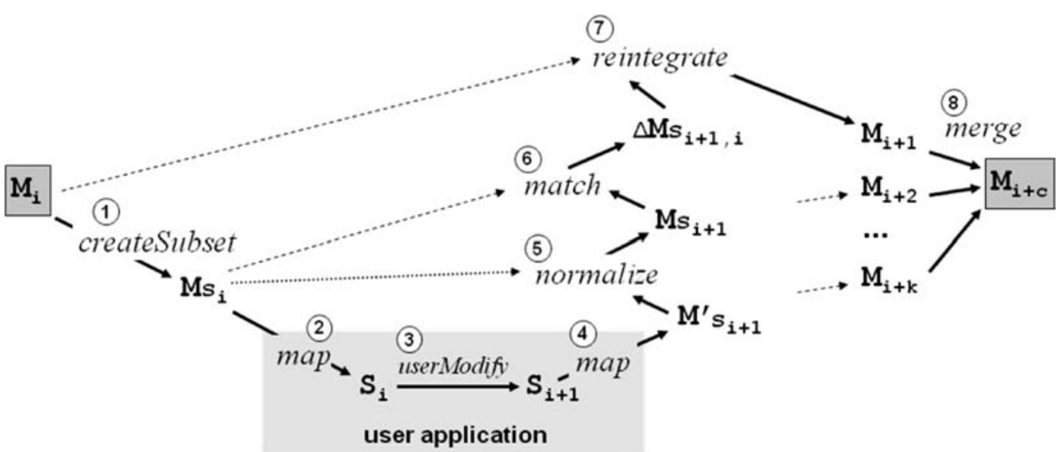

Figure 2. Data flow within the generalised collaboration scenario with temporary design states and required actions for roundtrip.

view that is formalized as a filter definition based on the Generalised Model Subset Definition Schema (GMSD, Weise et al. 2003). The GMSD schema is a (neutral) definition format for EXPRESS-based models, with special attention to IFC that allows the formalization of model views via object selection on instance level and view definition on class level. So the extraction of a model subset is done by removing (unselected) data objects, cut off or reducing references, filtering instances and attributes according to a model view (pre-) defined by a GMSD schema filter definition. This process is reversible enabling subsequent re-integration of the data into the originating model (cf. section 3.2.4).

3.2.2 *Normalisation*

Normalisation of the user modified model subset is needed for tackling the allowed different representations of the same data by the IFC model specification, thereby eliminating the structural inhomogeneity that may occur by the use of different CAD or other engineering applications.

As mentioned before, the complexity of the IFC model schema has increased significantly over the last decade. The current version of the IFC model, IFC 2×3 (IAI 2006) contains 653 classes and 1320 attributes. This means there exists over three times as many classes as the original IFC model marking a strong indicator for the growth in the domain coverage of the IFC data model. The effort involved in understanding the complete IFC model in order to implement it correctly becomes an important issue to the community. The studies of Lipman (2006), Pazlar and Turk (2006), Ma et al. (2006) and Amor and Ma (2006) indicate that the translation of the IFC data through a design tool has to be considered as incorrect. This means the design tools changes the model data only trough import/export procedures without any manipulation by the user.

Although we use model views that should provide only the model data that can be fully interpreted by the addressed design tool in order to avoid uncontrolled data loss the likelihood of structural model changes done by the application has to be anticipated in order to ensure model consistency. On the one hand the level of the model changes done by a design tool strongly depends on its function (drawing, numerical analysis, cost estimating etc.) and application domain, its internal model representation and the quality of its IFC schema implementation encompassed as application parameters. These influences can lead to serious structural model changes on object level, like object removing, fragmenting etc., with according effects to the objects references. On the other hand there is an influence to the level of the model changes by the users adjustment of the design tool that is not strictly related to his/her specific work task. This includes e.g. the use of different units of measurement (mm, m, kN, lb etc.) and different frames of reference (positioning of local and global coordinate systems, elevation of floor levels etc.) encompassed as representation parameters characterizing the local representation of the design. Unlike the application parameters that cause structural model changes on object level, the representation parameters influence the model on attribute level without structural changes of the model data. But both types of influence lead to different representations of the same data in the originate model subset provided by the model view extraction method and the model subset modified within the specific user work task by using the associated application. The normalisation method has to retract the unintended changes in order to ensure uniform representations of the model data over both model subsets referring to the originate model subset.

However, the normalisation process replaces the differing representations in the modified model subset by the equivalent representations according to the originate model subset. The substitution is based on predefined transformation rules derived from the application and representation parameters describing the expected model changes. Consequently this means to define a common agreement that concerns about the allowed types of representation over the complete data model with regard to the involved design tools and the preferred representation parameters.

3.2.3 *Model matching*

The matching method (step 6 of the generalized collaboration scenario on Fig. 1) has to identify the changes in the model subset done by the user within his specific work task. The identification of the model changes provides the basis for delta-based version management supporting a transparent and traceable design process. Thus matching acts like a redlining function with regard to BIM. Since model matching does not require nor involve specific engineering knowledge it is independent from the different engineering tasks.

The identification process is based on a comparison of the old and the new model (subset) versions carried out as an iterative exploitation of the object structure without considering its semantic meaning. Initial point of this process is the creation of two object sets: 1) a set of validated object pairs, established by using their unique identifiers and 2) the remaining set of unidentifiable objects. New object pairs are generated by evaluating equivalent references of already validated object pairs. Each of these assumed object pairs is then validated in an iteration cycle, depending on a weighting factor derived from the type of the reference responsible for its creation. In cases where ambiguities of aggregated references do not allow the generation of new object pairs attribute values are used for creating hash codes to detect identical references (Weise 2006).

3.2.4 *Re-Integration*

The re-integration method represents step 7 in the generalized collaboration scenario (Fig. 2) and becomes necessary because of the use of model views.

It has to invert the model view extraction process by adding removed data objects, restoring cut-off or reduced references and re-creating filtered out attributes. This process propagates the changes done to the partial model the designer has worked with to the complete BIM data according to the applied model view, the results of the comparison process and the adopted version management.

The re-integration process has to deal with structural and semantic problems whereas the latter cannot be resolved solely by generic server side procedures. Semantic problems typically occur when changes to a model view requires propagation of changes to another part of the overall model in order to restore consistency. Their resolution requires domain knowledge and respective user interaction by all involved actors carried out in a final merging process (Weise et al. 2004, Weise 2006).

3.2.5 *Reconciling and merging*

Reconciling and merging is performed at the next coordination point to take care of concurrently changed data by two or more designers. It includes the validation and adjustment of the modifications done by two or more designers in order to achieve a consistent new model state representing the beginning of the next collaboration cycle.

Unlike the other described PDM methods, this is a highly interactive process that cannot be fully accomplished in an automatic way. It requires an iterative agreement process between the involved engineers to resolve emerging conflicts. Thereby the agreement cycles have to be managed by a supervising instance in order to enable efficient conflict solving. The implementation of the agreement cycles can be realized by a collaborative work flow management system based on prior design knowledge, predefined agreement priorities and appropriate conflict solving strategies. An adequate decision support may integrate semantic analysis of the model data to detect conflicts evaluated by the supervising instance.

However, merging concurrently changed data to a new consistent model state with regard to the intentions of all involved designers is a highly complex process where world-wide research is still at an early phase.

4 SUGGESTED PDM-SERVICE INTEGRATION

Instead of developing yet another project integration environment we enable the integration of the basic PDM functionality into existing systems by providing access to according PDM services. The integration concept is based on the Service Oriented Architecture (SOA) approach dealing with flexible, reusable software components being deployed at runtime to provide the required advanced functionalities.

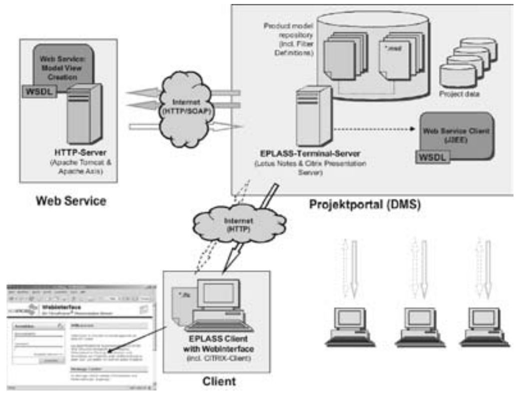

Figure 3. System architecture of the prototype implementation.

The product data functionality provided by each autonomous web service is well defined and can be described by its expected input and its generated output information according to the developed executable methods. This is done by using the Web Service Description Language (WSDL) specifying the allowed requests to the web services and the respective response messages, whereby product model data are treated as large data sets in much the same way as document files. The communication between the client applications and the web services is based on the SOAP Protocol which uses XML for data representation and HTTP for transport.

All product data management services are being realised as *stateful services* using the WSRF model (Banks 2006), in order to take care of their interdependencies and their need to interact with the shared BIM repository. The required transaction and resource management will be combined with the management functionality of an existing project environment, thereby enabling consistent and comprehensive role-based support of the collaboration processes. The integration of dedicated service clients complements the integrated portal based design environment.

The suggested system architecture is exemplified on the basis of the prototype implementation of the model view creation service (Fig. 3).

The according model view creation process is represented in Figure 4.

5 CONCLUSION

The goal of the presented work is (1) achieving and validating the feasibility of integrated IFC-based product

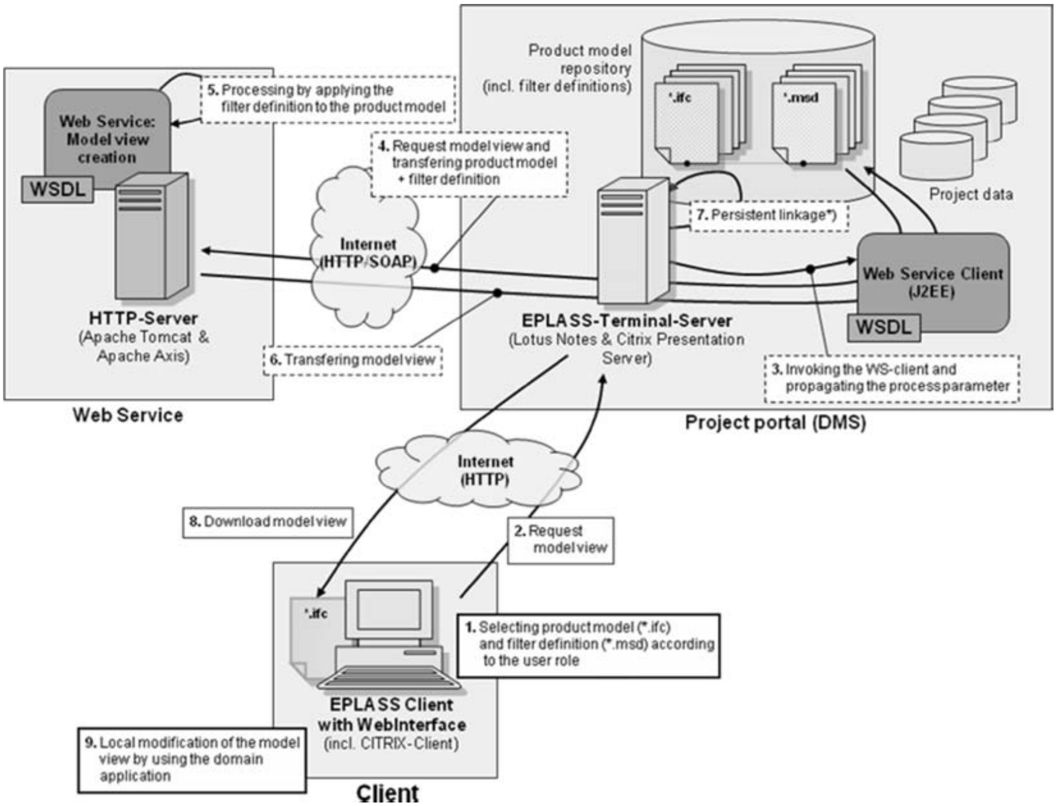

Figure 4. Principle schema of the model view creation process including communication and actions within the prototype system architecture.

model and document management services in the practical portal based design environment of the project partner SEIB ITC, and (2) realisation of generic methods that will enable third party vendors to use and adapt the product data management functionalities provided by the web services to their specific requirements. The paper described the fundamental PDM methods and presented an early prototype implementation of the outlined approach.

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Industrialised production

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Simulation of construction logistics in outfitting processes

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ABSTRACT: Construction logistics comprises planning, application, coordination and supervision of material flow to, within and from construction sites. Good construction logistics on construction sites saves time and construction costs (Boenert & Blömeke 2006). To plan construction logistics, numerous interferences between construction site configuration and construction work has to be considered. In particular in outfitting processes, their countless possible work sequences and many involved companies govern production logistics. This complex system can be analyzed by simulation. Nevertheless construction sites are often unique, so that qualified experience and a well educated guess are required to quickly find useable solutions. Depending on the chosen starting point and the planner's intuition, quite much effort is needed to finally determine a satisfactory solution. The represented research focuses on analyses of logistics strategies in the field of industry and stock inventory management by simulation in order to find a first feasible solution and to improve the construction logistics of outfitting processes.

1 INTRODCUCTION

In the last years science and practice have become very aware of the possible improvements by better construction logistics. Several studies of outfitting processes on German construction sites pointed out, that a lot of time is spent for non-productive actions (Guntermann 1997). Approximately one third of the total execution time is consumed by logistic processes (see Table 1).

Reasons for the high amount of non-productive actions and consequently disturbed work flow on construction sites are insufficient planned and non-coordinated logistic processes. For example disorganized material storage causes extra time for the search of material or to rearrange storage areas. Traditionally in most companies, construction logistics tasks are shared and performed in practice by several persons, of whom quite a few are also occupied by the construction process itself (Boenert & Blömeke 2006).

Table 1. Time slices of total work time (Guntermann 1997).

Type of activity	Percent of total work time	
Main work		30.9
Logistic affected processes		29.9
Ways	14.1	
Transport, hauling	8.9	
Rearrangements	5.8	
Material search	1.1	
Miscellaneous		39.2
Absence	19.8	
Personal-based interruption	10.3	
Failure-based interruption	3.5	
Others	5.6	

2 APPROACHES IN CONSTRUCTION LOGISTICS

2.1 *Development of construction logistics*

Above all logistic planning for construction sites is a big challenge for all parties concerned. In this context one often refers to the difference to stationary industry. In construction industry products and production conditions are unique, they are depending on weather conditions, and numerous participations are involved in construction projects. These facts are especially mentioned by practitioners.

In research, however several approaches exist to transfer logistic methods and solutions from stationary to construction industry, in spite of above mentioned facts. Already in the 1980s the two terms logistics and construction industry were used in combination. This period is characterized by launching orderliness to constructions sites. In the middle of the 1990ies non-value activities were in the focus of international research. New concepts for logistic activities dominate construction industry. There are efforts to pool planning and applying logistic tasks on construction sites. At the latest in the beginning of the 2000s the term construction logistics was established. Holistic logistic solutions, e.g. integration of logistic aspects in preparation of construction work and supply chain management, are indicating for this state of development. Detailed statements to construction logistics development are found in (Weber 2007).

2.2 *Simulation of construction logistic processes*

Along with further development of construction process simulation the simulation of logistic processes on site became more attractive. First approaches date from computer-aided site mobilization planning, e.g. the European research project DIVERCITY (Tawfik & Fernando 2001). Main point of that project was to organize temporary mobilization elements as bureaus and storage areas, to minimize ways between them and in consequence to reduce handling costs.

Other approaches are based on petri nets to simulate selected construction processes, e.g. assembly of prefabricated elements or earthwork processes (Chahrour 2007). Modeling and analyzing of logistic processes was not the primary goal, but to model the construction process is was necessary to regard logistic elements like means of transportation and hoisting equipment.

First approaches in Germany to principally simulate logistic processes on construction sites were represented by (Weber 2007). Weber regards the complete material flow from the entry on the construction site to the point of demand. Latter he abstractly describes as construction stage. Thereby the main focus is on dimensioning of delivery and storage areas and mechanical transport systems, e.g. cranes or builder's hoist. Manual transports are secondary. Using the model it is possible to compare several characteristics of selected logistic feature. For example delivery logistic strategy can simulate many small as well as few large delivery packages. Objective criterions are to minimize ways of vehicles and pass-through time. All experiences were drawn from one real construction site. Therefore, as Weber conceded himself, the results are not universal.

Even though a great optimizing potential from logistics exists in outfitting, these processes were merely taken into account in simulation studies.

3 SPECIALITY OF LOGISTICS IN OUTFITTING PROCESSES

3.1 *Characteristics or outfitting processes*

Outfitting processes are characterized by a high density of workgroups. This applies as well in spatial as in temporal respect and induce a high number of workers at the same time and the same place on construction sites.

Often various possibilities in work sequence exist. Both within a single gang and between several workgroups huge variability is given. Within a single gang variability is caused by feasible execution types, work routes and sequences (spatial variability). The constitution of workgroups is variable, too. Consequences then are a different duration of work (temporal variability). Between several gangs there can be set different sequences of work, the size of work areas (spatial variability) and also temporal, e.g. parallel or successively, distances (temporal variability). A relevant higher number of suitable possibilities exist to yield a defined outfitting scope of work in comparison to structural work.

3.2 *Logistics of outfitting processes*

In general in practice each gang is responsible to provide itself with material and to make necessary utensils available.

Merely the providing of general construction requirements is done by superior levels, e.g. building owner or general contractor. It constitutes a main pattern for logistic processes. Beyond it the construction requirements are highly variable in type and spatial and temporal view.

Construction requirement types for outfitting processes are mainly various in view of vertical and horizontal material transport. For vertical transport cranes are most important. Elevators, lifting platforms or high lift trucks are also worth being considered. Horizontal transport can be done by forklifts, mobile transport containers, mechanically or manually powered pumps. Manual transport in horizontal and – at small scale – in vertical direction is possible, too, and common for outfitting processes.

Spatial variability is indicated by alternative positions of construction requirements. In comparison to structural work, the working area during outfitting processes is quasi atomized, because innumerable positions are feasible. Furthermore and especially in outfitting the rescheduling of storage area, the rearrangement of means of transportation or other necessary utensils is normal. Also accessibility often changes. These facts are mostly caused by the work process itself. For example a room, in which material was stored, can no longer be used as this, as soon as outfitting processes in this room start, or a stairway can not be entered, because of floor finishing works.

Temporary limited existence of storage areas and positions of construction requirement indicate temporal variability. This is also caused by the working process itself. Sometimes use of lifts and other means of transport is restricted. For example after finishing the façade elements, outdoor elevators are dismantled, and mostly it must be switched to an inside elevator.

In view of logistics, especially the delivery, outfitting processes are quite different from structural work.

Whereas material supply for structural work processes requires delivery in large units, during outfitting the material is delivered in much smaller units. The cargo capacity of vehicles is not exhausted, sometimes the freight is destined for several construction sites.

Planning the storage areas allows much more variety because of numerous feasible solutions. Furthermore there is more freedom of meet site requirements and use different logistic strategies.

4 SCOPE OF THE RESEARCH

To improve the situation on typical construction sites (see Table 1) it is necessary to plan and to implement a usable logistic solution. The available optimizing potential is indisputable. Over 30 percent of total working time is influenced by logistics. Economization is estimated at over 10 percent of total working time (Boenert & Blömeke 2006).

The straight interrelation between construction processes and logistics as well as the variability of logistics in outfitting processes and of outfitting itself makes logistic planning a real challenge.

It is not surprising that a high number of possible solutions exist for several logistic functions, e.g. delivery, storage, transport of material. Partial optimization might be counterproductive, if improvement is only considered for one special problem or situation, where this then badly influences other tasks. For example, the arrangement of an additional unloading area might reduce waiting time for delivery vehicles on a construction site, but may require an additional crane, and thus causes additional costs. Or if material storage is decided to be very close to the workspace, a lot of rearrangement activities might be required. Such conflicts of interest are not unusual in logistics. They result in problems of multi-dimensional optimization.

The presented research starts out from here. Strategies for the achievement of objectives have been developed in several fields of logistics. These are standardized procedures to achieve a special aim and to minimize conflicts of interests. Classical examples for logistic keywords are just-in-time delivery to reduce goods in stocks or first-in-first-out to avoid outdated goods in stock. But there is still the question, which strategy or combination of strategies is suitable for a particular construction project with its actual character.

Pure mathematical optimization is not yet suitable for the complex task. Common methods for iteration are used to find better solutions. Therefore it is not easy to quickly find a best solution. It depends already on a favorable entry configuration. And in practice still much experience and intuition are required, which then together with good luck sum up to an adequate solution.

The research focuses on analyzing suitable strategy combinations for several characteristics of outfitting processes to find a first feasible solution for further detailed planning and improvement of construction logistics.

To analyze such complex systems, which are formed by working processes, by logistics activities on construction sites and by their interferences and influences, simulation is a suitable tool (according to VDI Verein Deutscher Ingenieure 1996).

5 A MODEL TO SIMULATE OUTFITTING PROCESSES

5.1 *General demands*

To analyze suitable strategy combinations for outfitting, it is necessary that the used simulation model respects the specialties of outfitting processes. Besides the above mentioned and in comparison to stationary industry, outfitting is indicated by non-permanent working areas. To respect the exact location of working areas is a general condition to model logistic activities with sufficient accuracy.

The chosen model will in an easy way enable to simulate outfitting processes with several characteristics, e.g. employment or working schedules. Models accommodations to a special construction site should be possible without programming. The same is valid to regard several logistic strategies.

5.2 *Used simulation model*

The presented approach is starting out from a simulation model which is used to display construction processes, especially outfitting processes. The used simulation model is a constraint-based model which has been developed by König et al. to analyzed construction processes and work orders (König, Beißert, Steinhauer & Bargstädt 2007). The fundamental idea is that work steps can only start, when certain constraints are fulfilled. This model is implemented by the Simulation Toolkit Shipbuilding (STS) of the SimCoMar community (Steinhauer 2007), (SimCoMar 2008) and uses the discrete-event simulation program Tecnomatix Plant Simulation provided by Siemens PLM Software.

Users are enabled to model and simulate several outfitting processes and basic logistic activities by the including STS simulation framework without programming. There several STS-components are available. For example the resource administration component manages, assigns and releases the required resources of work steps. All STS components are interlocked. They simulate work steps and further activities to finish construction work in order to user's guidelines (König, Beißert & Bargstädt 2007).

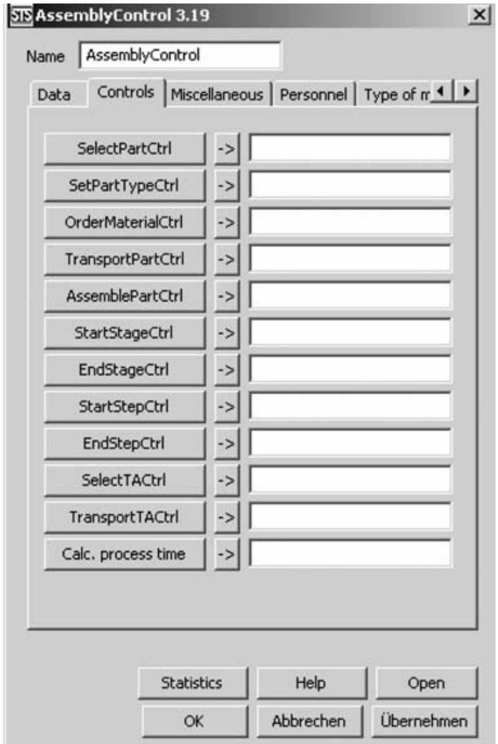

Figure 1. Interface of the STS Assembly Control component.

5.3 *Essential expansions*

To integrate detailed logistic activities for construction sites some STS components are adapted and other new components are implemented. Adaption of existing components is done by using their interfaces.

For example the STS Assembly Control component enables to call different methods before starting a work step and after ending it. All actually programmed and initiated methods are collected in a newly created logistic control component. The new component manages all logistic activities in interaction with existing components.

Further adaptation was required to record necessary data during the simulation run in order to analyze the effects of several logistic strategies. Additional modules are implemented too, which are often used to model construction site logistics. e.g. a special delivery area.

6 SIMULATION OF LOGISTIC ACTIVITIES

6.1 *Logistic control component*

The implemented logistic control component collects several methods to manage logistic activities

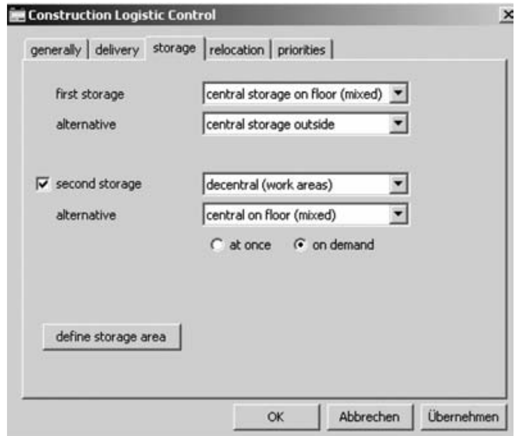

Figure 2. Logistic Control Dialog.

according to different logistic strategies. Such strategies are available for delivery, storing, relocation and clean up.

Currently implemented delivery strategies are delivery of all material at the beginning, by schedule, at the beginning of activities of a workgroup, on call or by a defined criterion, for example delivery according to stage of construction.

Available storage strategies are central storage outside, storage on floors inside and storage close to the work area. The first two strategies can further be divided by a common storage area or different areas for each workgroup. The definition of storage areas can be done by the logistic control component also. It is possible to define temporary areas by specifying the valid time period. Furthermore storage processes can be divided into two separate processes, for example first storing the material in a central area on one floor and later shipping it to a storage area on another floor.

Relocation rules are shifting the material to the next unobstructed space inside or outside the actual work space, to the next storage area or according to another storage strategy. For empty pallets special areas can be defined.

As clean up strategies are available immediately clean up, e.g. as soon as a pallet or carton is empty, or clean up on demand, e.g. work space must be cleared for a work process. Empty pallets can only be taken to storage areas, other packaging material to the waste disposal point. Whether the storage of empty pallets is allowed in certain areas or not, can be defined as well as areas only for empty pallets.

Furthermore the setting of priorities of logistic activities and allocation to workers can be done by the logistic control component. For example material transport to work areas is preferred to clean up processes. Or unloading of arriving vehicles can be done

Table 2. Summary of important logistic methods.

Method name	description
search storing area	searches a storing area for storing, relocating or cleaning up according to a chosen strategy
cleanup	generates transport task of empty transport devices to pallet storage or to waste disposal areas (e.g. empty cartons)
suspend work area	forbids storage in working areas during work
setaccessibility	temporarily/permanently blocks ways in an area after work steps if necessary (e.g. floor covering)
check work area	checks a work area for stored material and generates transport tasks to another storage area if necessary

by a logisticians, by the gangs for which the arriving material is destined or by any workers on site. Choosing the strategies and all other settings can easily be done by a dialog box without extra programming. Within this dialog the storage areas can be defined too.

Methods inside the logistic control component generate and control logistic activities, for example suspending working areas for storing, cleaning up empty pallets or searching storage areas according to the chosen storage strategy. Table 2 shows a summary of the most important methods inside the logistic control component.

6.2 *Interaction between components*

All newly added logistic control methods interact with already existing STS components, especially with transport control and assembly control components. Connections by using component interfaces enable the user to model construction processes with and without using the logistic control component.

In general assembly control calls for logistic control and logistic control calls for transport control. A detailed description of interaction between all STS-components is found in (König, Beißert & Bargstädt 2007).

6.3 *Input data*

Input data are necessary to simulate the construction processes. They include data for delivery, assembly, work sequence and others. Independently of using the new logistic control component, the most important input data are shown in table 3. At the moment it is not yet arranged to generate these data in a CAD-program and directly transfer them to the simulation environment. They have to be generated and read in via XML-interface or typed manually into tables.

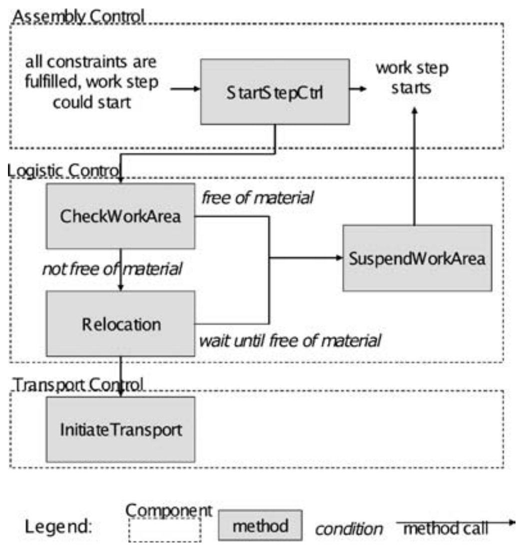

Figure 3. General interaction between control components.

Table 3. Important input data.

Input data for	examples
Delivery	Number, date of delivery Transportation device Dimensions, kind of material
Assembly	point of assembly, dimensions Workers number and qualification Assembly duration
Work order (constraints)	Order of work steps (on material and structural components) Order of assembly of structural components (needed predecessors)
Personnel	Number, working hours Qualification
Equipment	Number, location, working hours, technical data of construction requirement elements

To use the logistic control component additional data are needed to regard logistic aspects. These are information about required work areas, accessibility after assembly and information about logistic strategies (see chapter 6.1), storage areas and so on.

6.4 *Output data*

Standard output data are the utilization level of workers and of major construction equipment e. g. crane. To estimate the applicability of the chosen and combined logistic strategies, additional data are necessary. These data are automatically recorded by the logistic control component.

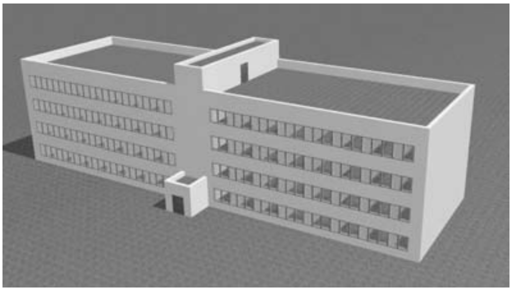

Figure 4. Simulated administration building.

Workers' occupancy is now recorded according to core work activities, material hauling, unloading/loading, restoring and clean up. Recorded vehicle data are the arrival on construction site, the beginning and ending of unloading. Analysis of vehicles' waiting time and therefore evaluation of required unloading areas is now possible. Additional number of non-accomplishable store activities (because of storage area is crowded) is recorded. This is helpful to dimension the storage areas.

7 EXAMPLE: STORAGE STRATEGIES

7.1 *Description*

The examined example is taken from the simulation of outfitting processes of an administration building with four floors. The following outfitting tasks are given: drywall construction, wallpapering and paint work, flooring and assembly of coffered ceiling.

All work items are simulated taking only their main process. For example drywall construction stands for the assembling of all plasterboards. Secondary work steps like cutting to size or feathering out are neglected. The work time of the main process is taken by the average overall value. Therefore the performance time of plasterboard assembly includes the performance time of all necessary auxiliary work steps. A more detailed simulation of work steps is possible, e.g. for analyzing assembly strategies. But in this first step of simulation it is suppressed.

Displayed scope of work starts after finishing the building shell. All floors are empty, except for the load bearing walls. After assembly foot point of installed material are closed if it is necessary, e.g. for plasterboard. At the end of the simulation all floor finishing is equal to the finishing of the ground plan. The building is divided into eight construction sections, two on each floor: left and right. All tasks are executed in all eight sections: first floor left, first floor right, second floor left, second floor right and so on. Work sequence within these sections is not limited, only the order of the workgroups is fixed. A new gang starts working in a construction stage after the predecessor has ended. Possibly stagnations due to different working speeds of gangs are accepted.

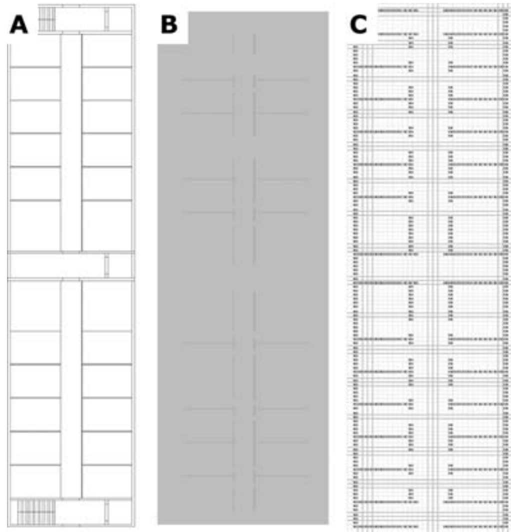

Figure 5. Floor plan (A), screen shot after drywall assembly (load bearing walls are not shown) (B), underlying occupancy matrix (C).

All floors can be reached only by stairs at the ends of the building end. Access to the building on first floor is next to the stairs as well as an additional entry in the middle of the building. The personnel lift can not be used during construction time, all transport downstairs and upstairs is done manually by resources, e.g. stair-qualified luggage cart.

7.2 *Strategies*

Here an exemplary analysis of several storage strategies is shown. To analyze storage strategies the settings of other logistic strategies are boundary conditions.

(a) The delivery of material is according to the construction section for each gang before start of work in the section (delivery strategy). Exact delivery dates are not known before starting the first simulation run. According to work sequence and other influences during several simulation runs the exact start date of a construction section is variable. Therefore all material is made available at the start of simulation and is called on demand (when a new section can be started). Then delivery can be realized.

(b) Empty pallets are instantly cleaned away (clean up strategy). Material which block someone's way, e.g. a construction work step, is rearranged according to storage rules (relocation strategy).

Because of blocking the active work area for further storage processes, it is guaranteed that new storage areas are outside of actual work areas. If there is no storage place, the beginning of an active work step is delayed, until there is a place for the interfering material and the actual work area is freed of material.

(c) All logistic processes are done by workers of the actual gang. Unloading of freight vehicles has the highest priority, next favor processes are to deliver material to its storage area. If a freight vehicle arrives on the construction site, no new work steps start before the process of unloading and storing material is finished. Hence a quick release of unload areas is guaranteed and traffic jams at the slip road to the site and at outside traffic are prevented.

(d) Assembly processes are preferred to transport processes. Because the assembly can only start when the required material is available, the corresponding working processes start straight from transport processes. If transport activities have a higher priority than assembling, all material would be distributed to their point of assembly before the first assembly starts.

All aforementioned settings are fixed conditions to analyze the applicability of several storage strategies. Exemplarily the comparison of two storage strategies is demonstrated.

Strategy one is to store all material on central storage areas on every floor. The storage area is located in the centre of each floor near the future lift vestibule and the four neighboring rooms. The storage can be used by all workgroups. If no storage area is available (occupied or needed for a work process), the material is stored outside of the building in a central storage area.

Strategy two is to store all material close to work areas. Storage areas are dispersed over all floors according to the work area locations. In case of occupied areas or areas needed by other processes, the material is stored at a central floor storage area.

7.3 *Evaluation*

To compare the effects of central storage on floors to decentralized storage areas next to the assembling points two simulations were run. During both runs all important data were record.

Abstraction of construction processes into a single main process doesn't allow the comparison to situation on German sites (table 1). Because only one type of material is required, the number of transport activities and ways is strongly reduced. This fact explains apparently the very high time slices of main work in the simulated example too. Still a direct comparison of both strategies is possible.

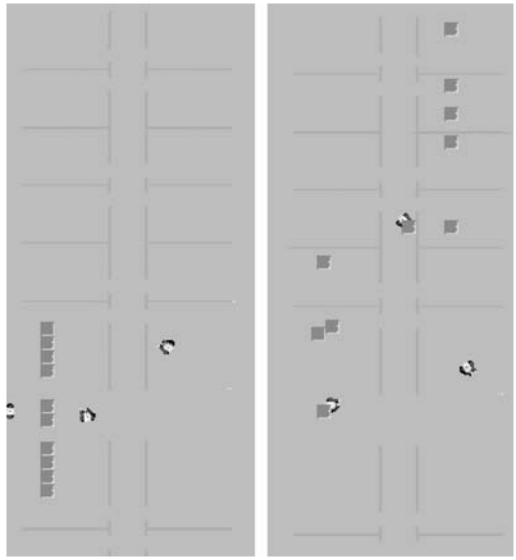

Figure 6. Screenshots of central storage strategy (left) and decentralized storage strategy (right).

Looking at the sum of all workgroups the work time slices increased from 86.8 percent (central storage) to 87.1 percent (decentral storage). At first sight this seems to be a merely noticeable improvement. The reason for this is a too high abstraction level. The simulated execution time includes execution times of all necessary work steps, transport activities are only caused by the main process. That means that not all required ways in practice are realistically simulated and the relation between work and logistic activities is displaced on behalf of assembling. The displayed strategies mainly influence the distances between storage and work areas. A more detailed simulation of construction processes increases the proportion of ways, whereas the total assembling time is unchanged. Effects of changing storage strategies are more clearly pointed out by more detailed modeling and simulation.

Table 4 shows the changing of time slice of selected logistic activities by decentralized storage instead of central storage. The shown values are average values over all gangs. The result is a reduction of time slices caused by logistics by 19 percent by using decentralized storage at work areas instead of central storage on floors.

Unloading time and ways between working areas are approximately the same. The differences are caused by changing work sequences within construction stages because of several relocation activities.

Improvement of logistics of a single workgroup is partially different from the average values. Reductions of time slices range from 43 percent (drywall construction) to 34 percent (wallpapering) and 11 percent

Table 4. Important input data.

Logistic activity	central storage	decentralized storage	improvement
Material transport	3.68	2.86	22%
Storage	0.22	0.23	−4%
Relocation	0.01	0.03	−70%
Clean up	0.19	0.20	−5%
Total	4.10	3.32	19%

(flooring) and finally to as low as 3 percent (coffered ceiling).

The very low improvement of logistic strategies in coffered ceiling is caused by the way of modeling these work activities. Because of required mobile scaffolding material, a storage next to the work area is not possible. Storage at the scaffolding is not modeled yet, so there is barely a difference of distance between work and storage area by using another strategy. On the contrary a deterioration of relocation actions is ascertained. Decentralized storage caused more than twice as much relocation activities. These fact points out that one single storage strategy can not improve logistics all for workgroups in that way. Further research has not to strive for one global strategy, but it has to differentiate according to different kinds of working processes.

Analyzing the decreasing range of logistic time slice reduction from drywall construction to flooring, another fact is realized. Due to not harmonized working speed only drywall construction is undisturbed. All following gangs catch up on their predecessors. Wallpapering is hindered by drywall construction in the 7th of 8 construction stages, flooring is already blocked after the 4th stage. Thus arises waiting time, the percentage of work and logistic time slices decreases. That is evidence that improvements are accessible by using logistic strategies and they correspond to the level of optimizing the work sequence.

8 DISCUSSION AND CONCLUSSION

Logistic strategies for outfitting processes can be evaluated by a simulation model. This has been developed. Exemplarily two strategies are compared to store material. Their applicability is evaluated by looking on workers' average utilization. It shows the general aptitude of the model for simulating and optimizing the logistic aspects of construction processes within a construction site.

A realistic simulation model has to take care of a multitude of influences and parameters. Quite a few of them have been fixed in the first approach. Step for step more features, effects and parameters must be liberated and adjusted to realistic behaviour. For example material is not stored only on floors but also on scaffoldings.

Construction processes are variable in many ways. Some processes do not require a working area which is completely free from other material. In these cases it might be sufficient, if a certain surrounding area is free from stored material. Such different demands of logistic conditions indicate different suitable logistic strategies. There is no evident global logistic strategy, which is qualified to all kinds of working processes on construction sites.

Furthermore the complexity will be increased by considering other influences, for example different ground-floor plans, construction site configurations and work sequences. Equally the examples to analyze the applicability of logistic strategies will be developed to a higher degree of reality. Within the demonstrated example all workgroups are undisturbed in their actual construction activity. In practice available work areas are more limited and influence by other gangs.

The consequences of different ways of process modeling and different accuracy on inherent results must be analyzed too. That effects the degrees of abstraction for working processes or of correctness of input data. Furthermore the required accuracy of path finding must be checked on.

The simulation model has proven that logistic strategies differ in their suitability for construction environments. It is intended to generalize the advice to the applicability of logistic strategies, where the research gives reason for common underlying patterns for the optimization of the logistics on construction sites. Finally, undisturbed work flow, better resource utilization, shorter construction time and cost savings are at stake and can be captured by combining sophisticated simulation models for construction and logistics.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

A review on intelligent construction and its possible impacts on the industry

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ABSTRACT: The trend nowadays is towards "intelligent" homes, continuously fitted with more and more technologies. This new era means additional comfort and efficiency in buildings, but also means, facility management of commercial properties is becoming more complex. Building operators are therefore relying increasingly on the advantages of wireless communication for the efficient management of the complete supply system. To improve safety, for example, rooms, fire protection doors and elevators can be interconnected. The automated management resulting from wireless communications offers clear cost savings, because it optimizes the deployment of janitors and security personnel, and ensures that the maintenance, security and performance of the building are never endangered. Wireless communication is already becoming established in commercial facility management today. A similar growth pattern is expected for private homes. The market for "Intelligent Constructions" offers many opportunities. In this paper, previously done works on the major issues related with Intelligent Constructions, such as, system concepts and components; technologies and services; current and future applications; and impacts of wireless technology on overall performance and efficiency of AEC/FM industry are reviewed in a broader sense in order to enlighten the possible contributions of Intelligent Constructions on the construction industry.

1 INTRODUCTION

Intelligent Constructions utilizing the latest technologies to improve the building environment and its functionalities, are offering extensive productivity and higher comfort levels for end-users, together with lowered individual investment costs and following operational costs. The technologies that are currently in use are collecting various information from different sources within a building and process this knowledge to fulfill centralized control over the functions of the building systems in an integrated manner (USCCTP 2003, CABA 2002).

An efficiently integrated system enables detailed access and control over the building systems to maintain overall operational efficiency, while exchanging information among them. This information can then be used to manage local environmental facilities and activities, effectively and securely. The integration of these systems can only be done by a reliable communications infrastructure, containing a PC at the remote control center, for performing information processing and communications activities among different building systems. The most important features that should be guaranteed within the communications infrastructure are redundancy, flexibility, security and interoperability of information generated and used within different building systems, like HVAC systems, fire and life safety systems, elevators and lighting systems etc. The full interoperability of these data among building systems will be a requirement in the near future, which is a must for the ultimate success of the "Intelligent Constructions" projects.

Major functions that can be performed in an integrated manner, within an "Intelligent Constructions" can be categorized in three groups as listed below. The role of wireless and wired communications technologies, benefits and challenges of "Intelligent Constructions" are also specified for these functions remote control functions.

The cost effectiveness, efficiency and reliability of ICT based Facility Management systems in "Intelligent Constructions", comes from the centralized remote control functions and distributed data collection/processing/evaluation and control features of the communications infrastructure, comprising wired and wireless devices. When the communication infrastructure backbone fails, the distributed control and the distributed diagnostics will ensure the overall functionality of the ICT/FM system for the intelligent building (IFMA 2007).

New communications/control protocols and standards are evolving for better reliability, efficiency and interoperability of the remote control systems. The currently existing standards, which are not fulfilling the complete requirements for interoperability but still have widespread usage are, the BACnet, LonWorks and Zigbee/IEEE 802.15.4 protocols (ZigBee Alliance 2007, Kinney 2003, Cook & Das 2004).

Especially the wireless communications devices play an important role wherever central activation or deactivation of embedded sensors and control devices is needed in a building. The process always provides cost effective and reliable solutions, for example, through the intelligent regulation of heating, air-conditioning, entire elevator systems or solar systems. Control of house technology can be carried out either from a central service point, or in the case of a private home, the owner can use his mobile phone, to remotely control individual appliances, even a coffee machine or a stove.

2 SECURITY FUNCTIONS

Many of the applications which may exist in intelligent buildings are already commonplace, for example, the ability to access a building independently and securely outside the normal working hours is provided by conventional systems. However, the new systems in "Intelligent Constructions" should be acting more reliably and effectively compared to the conventional systems, via increased individual environmental control; via reduction in consumption costs through extended zonal controls; establishing remote control over building systems after-hours via computer or telephone interface etc.

All types of security systems such as, smoke detectors, excess flow valves, movement detectors, door sensors, electric eyes, or video monitoring systems can be controlled individually and all together remotely and automatically, in an integrated manner. For example, when smoke detector goes off, the elevators may automatically be blocked and the fire protection doors shut.

3 FACILITY MANAGEMENT FUNCTIONS

Facility Management is the integrated management of building systems and related hard and soft services. Hard services include such things as ensuring buildings HVAC systems are operating efficiently, reliably, safely and in compliance with specified ratings and regulations. Soft services include such things as ensuring that the performance of contractors (e.g. builders, electricians, machanics, cleaners etc.) are monitored and controlled regularly.

FM mainly concentrates on ensuring that everything in a building is available and working properly, while they are offering good quality levels of life for the occupants. The emphasis of FM is on the skills for managing the occupancy of a facility and how its use evolves and develops in response to the changing demands of the occupier.

Preserving a facility's conditions at higher levels is important for economy. Many more organisations are realizing every day that their business performance is closely related to how they manage their facilities and workplace assets. For example, facilities-related expenses have been noted as representing for most companies the second-largest operating cost, next to personnel, and their greatest capital asset.

IFMA defines FM as:

"A profession that encompasses multiple disciplines to ensure the functionality of the built environment by integrating people, place, process and technology (CABA 2002)."

Another definition made by British Institute of Facility Management is:

"FM is the integration of multi-disciplinary activities within the built environment and management on their impact upon people and workplace."

Some or all of these activities or aspects stated in these definitions can be monitored or performed only by using data-rich computer application programs. In recent years, FM has become a focus of attention for academics and practitioners at the same time. The former view it as a rapidly developing field that offers, amongst other things, rich sources of data that can be used to explain or develop new theories about how we manage buildings and other constructed facilities. The latter regard it as an opportunity for business or a way to control operational costs, depending on whether there is a primary interest in providing FM services or in procuring them.

Research emphasis in recent years that FM has been shifting from conventional methods for collecting a facility inspection data to IT-based methods for obtaining, managing and exploiting data that provide more effective solutions to keep facilities in a safe and servicable condition. The new IT appoach has promising a prosperous future for the "Intelligent Constructions" industry, by minimizing cost improving productivity and extending facilities life time by keeping it in good condition.

Changing trends in the delivery of FM for major construction developments point to a more strategic outlook for the provision of FM related services and resources. This implies that FM has moved from being a simple maintenance activity to a corporate investment initiative reflecting the provision of desirable and relevant work space to required demands of end-users.

3.1 *Computer Aided Facility Management (CAFM)*

Is the evolution of FM which is performed under IT support through the web-based or LAN-based environment. With CAFM, the functional processes in an intelligent building environment are accomplished independently (automatically), according to pre-adjusted values or parameters. All sensors, control elements, users and other technical devices are all integrated in a network, based on a bus system (e.g EIB/KNX or illumination (DALI) etc.).

The essential feature of strategic FM is that it is a continuous process and not a single-planning task. The activities covered by strategic FM can be categorized into three parallel processes as follows (IFMA 2007):

- Monitoring how the facilities are being used and managed in site assessments;
- Evaluating whether facilities are best serving corporate objectives in workspace conditions evaluation;
- Anticipating how facilities might better support the organization and respond to its changing needs through forecasting and projecting future space requirements and demands.

IFMA classifies FM responsibilities into several major functional areas, (IFMA 2007):

- Long-range and annual facility planning.
- Financial forecasting of facilities.
- Real state acquisition.
- Work specifications, installation and space management.
- Architectural, engineering and construction planning and design management. (AEC/FM)
- Operations and maintenance management. (O&M/FM)
- Telecommunications integration, security and general administrative services.

CAFM tools are often used by facility managers to track, control and report on facility information in following areas:

These are the initial data of the building that should be collected from the building's Design Office, Construction Firm and the Building Owner. This data will then be inserted into the CAFM application tool's database as the initial data, and this information will be the reference point for all other tracking, controlling and reporting operations that will be conducted later for online performance evaluations of the building.

Interoperability within the CAFM tools inputs and outputs is needed to be developed further. Architecture, engineering, construction, and facilities management (AEC/FM) are information intensive industries, and are increasingly dependant upon effective information technologies. Various computer tools are used to support almost all AEC/FM design and management tasks, and the information entered into all of these tools describes the same physical project. However, this information is passed from one tool the next by producing paper-based or electronic documents which can only be interpreted by people, who must reenter relevant information into the next computer tool.

Table 1. Areas to track, control and report on facility management.

Area	Information
Floor plans	Design & implimentation data
Building and property info.	Envelope, structural & equipment data
Space characteristics and usage.	Building Owner's data
Employee and occupancy data.	Building Owner's/User's data
Workplace assets	Furniture, devices & systems
Business continuity and safety info	Design & implimentation data
LAN and telecom info.	Design & implimentation data

This manual data re-interpretation and entry is a nonvalue adding activity, can often introduce errors into the project, and inhibits the use of better computational tools. To address this problem of information communication and exchange, the topic of interoperability has been taken up as one of the primary areas for research and development in IT for AEC/FM (Edum-Fotwe et.al. 2003).

The benefits of CAFM of an "Intelligent Construction" are summarised below:

- Better monitor, manage and control electrical and mechanical equipment
- store data on performance and energy use
- "Real time" data synchronization
- Accurate report data for managers
- Provide access to corporate applications, e-mail and intranet
- Improved access to O&M manuals, health and safety information and drawings
- Improved employee productivity by reducing double-entry data submission
- Include reduced energy consumption, lower maintenance and repair costs

3.2 *Maintenance management*

The European Federation of National Maintenance Societies define maintenance as: "All actions which have the objective of retaining or restoring an item in or to a state in which it can perform it's required function." The actions include the combination of all technical and corresponding administrative, managerial and supervision actions.

The major task to be performed through the maintenance and operation activities are:

- Planning operations
- Managing execution of operational and maintenance events

– Management of assets. (Parts, tools, equipment etc.)
– The database of the maintenance

Management system must contain the following initial information for maintenance:

– Maintenance service history
– Serial numbered parts/systems
– Reliability data of maintenance activities
– Maintenance and repair documentation

Basic maintenance areas and types are:

1. Building maintenance: Covers the preventive and remedial upkeeping of building components. (e.g. HVAC, electrical, plumbing, elevators, carpentry and painting).
2. Corrective maintenance: Maintenance performed in case of equipment or system failure. (Brakedown maintenance).
3. Cyclical maintenance: Periodically and regularly performed maintenance.
4. Preventive maintenance: Planned actions undertaken to retain an item at a specified level or performance. (Changing parts, oil removal, pressure/temperature control and adjustments).

These different types of maintenance all need specific information, which need to be collected by the sensors and mobile productivity tools and need to transferred to specific people or organizations.

3.3 *Building services*

Everything inside an intelligent building, which makes it safe and comfortable to live in, comes under the title of "Building services". A building must do what it was designed to do, not just provide shelter but also be an environment where people can live, work and achieve. It must be a space, which fulfils the performance requirements of the users, during the life cycle of the building.

Building services engineering is the engineering of the internal environment and environmental impact of a building. It includes mechanical engineering and electrical engineering, including: (Source: The Chartered Institution of Building Services Engineers)

– Energy supply: gas, electricity and renewable sources
– HVAC systems
– Water, drainage and plumbing
– Natural and artificial lighting, and building facades
– Escalators and lifts
– Ventilation and refrigeration
– Communication lines, telephones and IT networks (ICT)
– Security and alarm systems
– Fire detection and protection

Building services in regard of FM can further be studied in three major areas:

1. Property Management Services:
   – These are the businesses related services, related with cost and revenue
   – For this service, there is no need for physical presence in the building
   – These may be further divided into two groups as:
     i. Renter-oriented services (e.g contract management; procurement coordination; space planning/management etc.)
     ii. Owner-oriented services (e.g taxes; insurance; sales; accounting; legal services; procurement etc.)
2. Building Operations & Maintenance Services:
   – Service that requires frequent visits to the building environment.
   – These services are physically oriented with the building and requires technical competence.
   – O&M Services may be further divided into three groups as:
     iii. Utilities (e.g oil/gas; energy; water; drain etc.)
     iv. Technical operations (e.g heating & ventilation; automated services; Telecom and IT; envelope management; energy performances etc.)
     v. Maintenance (e.g. planned/preventive/ corrective maintenances; modernisation/ adaptation; reconstruction etc.)
3. Support Services:
   – Day-to-day presence in the building is needed
   – These services are oriented around people and environment and have the most direct impact on the users of the building
   – Support Services may further be divided into two groups as:
     vi. Facility services (e.g workplace moves; waste/snow handling; cleaning etc.)
     vii. Security services (e.g access control; boundary protection; safety services; fire protection etc.)

An intelligent building can be considered as an asset or an investment that needs to be maintained to ensure its optimal value over its life cycle. Building systems, such as roofing, mechanical, or electrical, usually have a shorter life span than their supporting structures. These services are in constant need of regular maintainance to ensure that they continue to function properly and that they retain their value and good appearance. Maintainance, as per British Standard 3811, may be defined as "the combination of all technical and administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function" (Glossary 1984).

Mottonen and Niskala (1992) reported on the categories of information needed in maintainance management form the findings of research aimed at creating an information system for housing maintainance and management in Finland. These categories include:

1. Information on the building and the whole property. This information is created at the planning, design and construction stage of the project. In the case of new buildings, it is practical to transfer these data directly form the information system maintained by the planner to the system that would be employed in facilities management. This includes information on the site and buildings, spatial system (room, floor, etc.) and structural and technical systems.
2. Information on the operation and maintainance of the technical systems such as the estimated service life of equipment. This information is obtainable from designers, manufacturers and the literature in general. Some of the information is created or supplemented in the course of devices and structural elements, user experiences, or operating and maintainance costs.
3. Information on the maintainance organization, staff, goals and principles of the organization, maintainance routines and monitoring procedures." (Best et. al. 2003)

4 REVIEW OF SOME APPLICATION. EXAMPLES AND CASE STUDIES

Facility management in buildings benefits from the many advantages of wireless technology. The advantages for commercial building management are:

– Lower cost by automating all of the building's technology
– Better overview thanks to central monitoring and control
– Lower insurance premiums owing to improved security measures.
– Rapid and economical interconnecting of large multi-story buildings, since cables do not have to be laid and no complex installation is necessary.

The advantages for the private homes are:

– Simple handling, control and monitoring is performed with a cell phone
– High flexibility and more comfort, because household appliances and technology can be activated from away from the home
– Damage prevention thanks to early warning
– Increased feeling of security owing to 24-hour monitoring

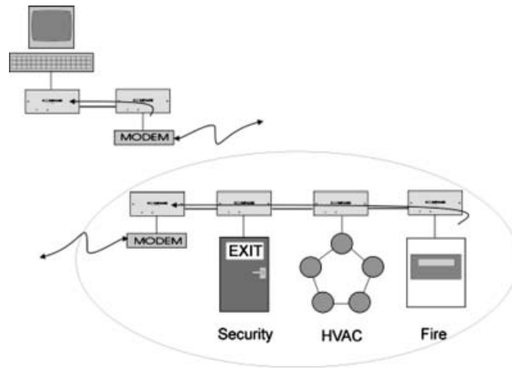

Figure 1. Remote building monitoring network diagram adopted from (Compass 2008).

– Homeowner keeps cost under control by avoiding extensive and messy installation work
– Alarm systems cannot be deactivated by severed cables or power failures

As an example, following diagram illustrates a remote control application for integrated functions and devices inside an intelligent building (Cook & Das 2004). As shown in Figure 1 below, the individual control systems within the individual buildings have been connected to form a single integrated system. One monitoring/controlling site can have access to hundreds of individual sites. Monitoring/Controlling systems use advanced, robust techniques that are based on smaller, less expensive, and much more abundant sensors. These data is again used to ensure optimal building performance by enabling control of building systems in an integrated manner and continuously recommissioning them using automated tools that detect and diagnose performance anomalies and degradation.

The monitoring site can dial up any of the remote sites and receive data. The modem Compass Points can store dialling information on up to 127 remote networks. If required, passwords can be configured to prevent unauthorised access to a site.

The individual control systems within the individual buildings have been connected to form a single integrated system. This requires only a single point-of-access, making management simpler and reducing costs. Alarms and event notification also come through to a single point providing faster response times.

This solution used Compass as the transport layer and to integrate the systems and ObSys to provide a GUI.

Delsing, and colleagues (2004) at their case study, have stated that, in future, almost all sensors in Intelligent Constructions, will be given the capability to become a node of Internet. To realize this concept, they have developed an Embedded Internet System, (EIS)

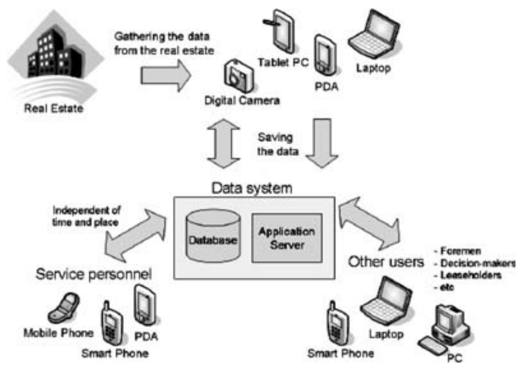

Figure 2. The examined process model. Adopted from Niemi (2007).

architecture for Internet Protocol enabled devices (Delsing et al. 2004).

The EIS architecture found applications at the AEC industry for workers security and health. Examples are, alone workers, workers at hazardous environment, heavy machinery operators, rescue workers etc. Another field is maintenance monitoring of machinery and equipment.

The third example of the applications that was reviewed in this paper was the work of Kimmo Niemi (2007), Institute of Construction Management and Economics, Tampere University of Technology, Finland. In his paper, Niemi described the possible methods for electronic maintenance information design and maintenance systems. With the help of mobile equipment and the wireless technologies available today, remote or local access to a real state to gather building systems performance data in real time, have become possible. The data is stored in the main database, which becomes available to all pares, during operations and maintenance processes.

The mobile users are having access to the real states by any available mobile device and data is gathered from the database by using the Wireless Local Area Networks, (WLANs), or the General Packet Radio Services, (GPRS), of the Mobile Telephony systems.

The system proposed and tested by Niemi (2007), as shown in Figure 2, above, is found to have sufficient usability and accessibility, as being a user-oriented process, (not device-oriented), the system is not depending on any specific mobile device.

5 CONCLUSIONS AND POSSIBLE IMPACTS OF INTELLIGENT CONSTRUCTIONS ON THE INDUSTRY

The financial impact of Intelligent Constructions on the industry will always be increasingly significant in all aspects, such as on capital costs, operational expenses, revenues and return on investment. Intelligent Construction technologies have become economically attractive, dependable and affordable. Their impact on the industry will be more influential, as the inter-working and interoperability of building systems develops further to become as widely accepted and implemented standards by manufacturers. The stakeholders are interested in different aspects of these financial implications. For example, the developers are more interested in the lower initial costs, while the owners and occupiers are interested in lower operational/maintenance costs. Intelligent Constructions will offer major opportunities to all stakeholders. The developers will experience higher selling rates at better prices, due to the additional value introduced by the Intelligent Constructions technologies. The owners/occupants on the other hand, will be happy due to the comfort, flexibility, high performance and lowered operational/maintenance costs. A building ownership is becoming more and more expensive, as the cost of energy and labor increases and work patterns change. The advantage of Intelligent Constructions technologies lie in this reality and its implementation in new buildings is becoming unavoidable, due to the increase of demands of building owners/occupiers for better functionalities and services to exist within the building environment. Intelligent Constructions projects will affect the design/construction/maintenance processes, all together at all levels. Therefore the developers/owners/operators/suppliers must make necessary changes in their current processes and approaches, to be able to take advantages that will be introduced by the Intelligent Constructions technologies. The stakeholders must re-evaluate their roles in the industry to adopt new approaches and practices in the light of evolving Intelligent Constructions technologies. The outcome of these changes can only be satisfying, if and only if all parties, that is the developers, owners, operators, manufacturers and suppliers, can create these changes in an integrated and co-operative approach, in close coordination and new regulations, which would cover the ICT based AEC/FM processes/practices/educations at discrete levels. The concept of intelligent construction starts from the design phase. The impacts of the design on the Facility Management aspect should be considered at the beginning phases of construction projects. Since the trend nowadays is towards "intelligent" homes, continuously fitted with more and more technologies this new era means additional comfort and efficiency in buildings. However, this transformation also means facility management of commercial properties is becoming more complex. Building operators are therefore relying increasingly on the advantages of wireless communication for the efficient management of the complete supply system.

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Design with architectural objects in industrialised house-building

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ABSTRACT: This paper introduces a research project with the aim to develop concepts and tools for architectural design, taking the ideas of "behaviour settings" as a starting point, to enable a more relevant holistic view in object oriented design of buildings. In this paper we introduce the concept of "architectural object" as a representation of a real "situation" involving people, behaviour, experience and environment, based on our idea that architectural design results in "situations" similar to but not identical to " behaviour settings". The purpose is to define a selection of possible configurable architectural objects that reflect the variability of situations possible to achieve using an industrialised building system. As architectural objects they shall be able to manage comprehensive information to be used in process tools for building design, production and facilities management. This paper presents a theoretical foundation for the use of architectural objects in a BIM environment. It also presents an analysis of the object structure that is applied to configure building projects in a company with off site production of volume elements, and proposes how these objects could be developed into architectural objects. The conclusion of the case study is that the company architects' view of the volume elements and their constituent design modules implicitly includes a conceptual model of user activities and phenomenal properties of the built environment. By formalising these concepts and making them explicit as part of the architectural object, the related information can be accessible to all parties in the processes, design, production and facilities management. The information can be used for gaining experience of the building in use, for simulation, as input to brief development, and other analyses of interest. In an industrialized building process including volume elements, architectural objects could be developed during the product development phase and applied during building project design as configurable design units. Future research will investigate further possible application of the idea of architectural objects, specifically to support the architectural design process in industrialized house-building.

1 INTRODUCTION

1.1 *Demands for industrialized building*

The building industry, in Sweden and internationally, has not shown the same development in productivity and industrialization as the manufacturing industry, much due to its project oriented operation and its favourable economy based on rising land costs (ECTP 2005, Egan 1998). The sector has also been criticized for quality failures and high costs. An industrialization of the industry has been pointed at as a measure of meeting these problems (Byggkommissionen 2002). A general opinion in the building industry is that a new and sustainable industrialization must avoid social and architectonic problems as those apparent in the industrialization efforts of the European Mass-Housing movement after WW II, e.g. the Swedish "one million dwelling program" in the 60's and 70's.

1.2 *Conditions for architectural design*

Architectural design has different conditions in different building processes. Traditionally, the building process is project oriented with a unique composition of participants in each project. The architect often has an initial role of defining the physical framework regarding function, materials and aesthetics, also affecting later decisions concerning technical solutions, production and economy. The work is governed by established routines and a clear division of responsibilities. It is characterized by strong time pressure and cost awareness in combination with limited possibilities of cooperation in early stages between design and production (Borgbrant 2003, Winch 2002).

Different strategies have been developed in order to handle problems related to lack of integration among stake-holders in the construction process. Turnkey contracting aims at facilitating early cooperation between design and production, but criticism has been raised due to its prime focus on production costs, neglecting life-cycle costs as well as architectural design issues (Byggkostnadsdelegationen 2002). Strategic partnering gives opportunities for work in integrated teams promoting reuse of experience and making the processes more effective (Miles 1996 and Kadefors 2002). Lean thinking is characterized by a strong customer focus where every activity that does not contribute to the product's customer value is questioned with the purpose to eliminate these from the process (Womack & Jones 1996, Josephsson & Saukkoriipi 2005). Object-oriented ICT makes information management more efficient, promotes integration of design activities and supplier networks, and supports individual customer choice (Olofsson et al. 2004, Wikforss 2003, Ekholm et al. 2008).

1.3 *The need for a comprehensive architectural view in the design process*

The shift from drafting oriented CAD to object oriented CAD enables new ways of managing and structuring design information (Eastman 1999). To an increasingly larger extent object oriented design tools are used in building design today. The development supports not only the production of drawings and visualisation, but also the development of BIM, Building Information Models. The combined project models are not only intended for use during the design phase, but also during production and facility management. The question of how to organise and exchange design information is a major subject of R&D today (ECTP 2005), exemplified by the IAI activity to develop the IFC standard of how objects and their properties may be exchanged among actors (Kiviniemi et al 2008).

However, not only the organisation of design information and how it is transferred between actors are problems, but also how the process is organised for creating the information. By enabling concurrency of contributions from different actors, the conditions for analyses of interacting factors, including a holistic architectural perspective are at hand (Anumba et al. 2007).

Modelling of buildings based on their constituent technical parts or functional relations among spaces, based on quantifiable specifications in building briefs, is supported today by object oriented design tools. But regrettably there is no software support for managing information about user activities which according to Ekholm (2001) would enable a more complete representation of the information generated and communicated in the design and facilities management processes.

1.4 *"Situations" as the result of architectural design*

Architectural design is since ancient days understood to include aesthetical, functional and technical aspects on buildings and built environment. Design does however not only affect the built environment but also intentionally affects the humans who use and experience it (Steadman 1975, Hillier 1996). The built environment sets conditions and gives possibilities for human activity; therefore it is relevant to conclude that architectural design handles man and building as a system (Ekholm 1987).

The environmental psychologist Roger Barker has introduced the concept "behaviour setting" to refer to a concrete unit of behaviour and milieu, with the milieu circumjacent and synomorphic to the behaviour (Barker 1968). According to Amos Rapoport "the environment can be conceptualized as a system of settings within which a system of activities take place" (1997). Christopher Alexander's similar concept "pattern" is described as a design unit with a strong emotional content referring to concrete systems of place and human activities and experience (1979). The inseparable unit of social activity and built environment, is named "fabric" by John Habraken in a similar attempt to capture the essence of the built environment in use, as a living organism (Habraken 2005).

These insights support our hypothesis that architects design with socio-technical systems or "situations" in mind. A situation can be described as human activity carried out in an environment with phenomenal values that support a specific mind-set and experiences during the activity. We call a situation seen as a design unit "architectural object". Architectural objects refer to situations of people, behaviour, experience and environment as a unit.

Even though the architect's work results in "situations", practical methods and tools that take these as a starting point are lacking. To describe activities and their properties as activity objects may be considered a step forward towards such tools. Eastman and Siabiris (1995) have developed a prototype CAD-system which illustrates the possibility to explicitly handle information about activities and their relations to the built environment. Ekholm and Fridqvist (2000) have shown a model schema where building space is defined by building elements, and how user activities can be related. Ekholm has designed a prototype information system for activity modelling as an add-on to ArchiCad (Ekholm 2001). Szuba (2005) presents another system as an add-on to ArchiCad, to be used for defining building spaces from activity spaces and functional requirements on the building. The question whether phenomenal values could be linked to objects composed of activities and built environment creating architectural objects is however yet unexplored.

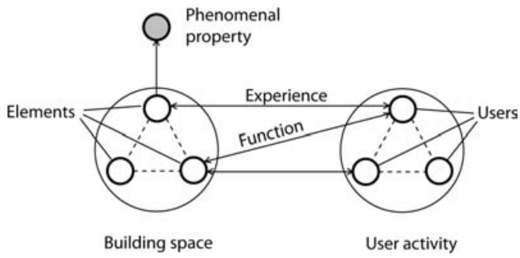

Figure 1. Constituents of an architectural object.

Object-oriented CAD-tools available today take as starting point objects representing building elements and spaces. In addition to that, an architectural object needs to include objects representing user activities and phenomenal properties; see Fig. 1.

1.5 *Aim of the research project*

This paper introduces a research project with the aim to develop concepts and tools for architectural design in industrialised house-building. The ideas of "behaviour settings" are taken as a starting point to enable a more relevant holistic view in object oriented building design. The purpose is to develop configurable architectural objects that reflect the versatility of an industrialised building system. As architectural objects they shall be able to manage comprehensive information to be used in information systems for building design, production and facilities management.

The research may be understood as a continuation of the group's earlier work concerning modelling of human activities in building design, e.g. the BAS-CAAD project (Ekholm & Fridqvist 1999), and the definitions of the concept of space, initiated by (Björk 1994), and further developed by Ekholm and Fridqvist (2000) and Ekholm (2001). The context for the project is firstly design of house-building projects for industrialised building, where we think the methodology with architectural objects may have the largest impact in a short time perspective.

1.6 *Aim of this paper*

This article deals with the theoretical foundations for the use of architectural objects in a BIM environment. It also presents an analysis of the object structure that is applied by a company with off site production of volume elements to configure building projects, and proposes how these could be developed into architectural objects.

1.7 *General research questions*

Achieving high architectural quality in industrial house-building regarding function, aesthetics and adaptability is a fundamental requirement on industrial house-building. Knowledge of how questions of architectural design could be integrated in process and platform development needs to be developed in order to strengthen customer focus and optimize issues on design with regard to e.g., function, aesthetics, buildability, logistics, environmental consequences and energy consumption.

The research questions in this project relates to process and platform properties and ICT-support, three areas of importance for architectural issues in industrial house-building:

- Could architectural objects serve as a tool in the development of processes for building platform development and building project design to support questions of architectural quality in concurrent engineering?
- Could architectural objects be a foundation for investigating functional and aesthetic versatility of the building platform, considering production engineering consequences, with the objective to enable high architectural design standards and adaptability to various customer preferences over time?
- Could architectural objects in ICT-tools support issues of architectural quality in process and product platform development and in the configuration of a specific building project?

1.8 *Methodology*

The project will build on the research teams' experience of how user activity and building could be handled in an integrated way as architectural objects to accentuate a use-centred perspective in the design processes. The aim is to develop prototypes for CAD-tools handling architectural objects in a BIM-environment. The project's specific focus is on the architectural design requirements on ICT-support in concurrent engineering for industrialised house-building. However this focus will be set against a firm theoretical framework covering also process and product design.

The research project will design a model for process and product development with related criteria for the organisation of object oriented information management for industrial house-building, focusing on its architectural design. The model will be built through literature studies, interviews with key actors, and empirical studies.

The interviews with key actors aim at completing the literature studies and address people involved in architectural design concerning traditional and industrial house-building respectively, as well as people in other industries with functions involving the gain of information on aesthetical, functional and technical customer requirements. Design support with architectural objects will be tested using object-oriented CAD-tools in a BIM-environment. Specific objects and routines needed in the development may also be created by the researchers using the object language GDL in ArchiCad. We will however cooperate with software developers for supplementary competence.

The work will be organized in two steps. A thorough mapping of the information flow in product development and building design at an industrial house-builder will be conducted. The product portfolio and its modular components will be studied from the point of view of functional grouping and assembly, and how production flow and quality confinements can be organised. Based on this, suggestions will be developed for how architectural objects could be implemented in the routines for product development and configuration in the company.

The second step is a profound study concerning feasible demands on product and process platforms in accordance with architectural design. This step will include development and testing of prototypes in cooperation with software developers and design consultants.

1.9 *Organisation*

The project is part of the Lean Wood Engineering program initiated by the Swedish Governmental Agency for Innovation Systems, VINNOVA, in collaboration with 12 industrial partners from wood manufacturing industries as well as the building sector. The work will be carried out as a post graduate project at the division of Design Methodology at Lund University, Lund Institute of Technology. Cooperation is intended with companies involved in industrial house-building, e.g. those participating in the LWE-program.

1.10 *Expected results*

The project will develop a methodology and prototype software for handling object oriented ICT support in industrial house-building with focus on demands set up in the context of architectural design, emphasising customer values as function, aesthetics and adaptability.

The project results should be of significant importance to designers and companies within the field of industrial building, particularly for dwellings, supporting the development of company specific process and product platforms and the realization of actual building projects.

2 THEORETICAL FRAMEWORK FOR ARCHITECTURAL OBJECTS

2.1 *Behaviour setting*

A behaviour setting, according to Barker, "consists of one or more standing patterns of behaviour-and-milieu, with the milieu circumjacent and synomorphic to the behaviour"; Barker mentions e.g. "a basketball game, a worship service, a piano lesson" (Barker 1998). The synomorphic property is explained as "an essential fittingness", i.e. behaviour and milieu are fundamentally coordinated. Behaviour settings consist of behaviour-milieu parts, i.e. "things and occurrences that have both physical and behavioural attributes" (ibid:19). A behaviour setting has a certain degree of interdependence of its constituent parts, and an independence from other behaviour settings (ibid:23). Attributes of behaviour settings include among others geographic and temporal locus, occurrence and duration, occupancy time, functional position of inhabitants, action patterns, and behaviour mechanisms.

2.2 *Architectural object*

In section 1.4 an architectural object was described as a "situation" involving people, behaviour, experience and environment. A definition of an architectural object may be developed in relation to Barker's "behaviour setting" concept and to the "space" and "activity" schemas developed by Ekholm and Fridqvist (2000) and Ekholm (2001) respectively. An architectural object should not be seen as identical with a "behaviour setting", but as an architectural design unit that may support the design of certain activities and their related built environment.

A tentative conceptual schema for an architectural object has been developed, see Fig. 2 below. In the schema an Architectural object may be functionally composed of other architectural objects, and consists of a human Activity, located in a Natural or built environment, the latter seen as a Construction entity space. The Activity has Duration and Relations to other Activities. It may be functionally composed of Activities, and is carried out by Persons using Equipment. An Architectural object has none or many Phenomenal property experienced by a Person. A piece of Equipment has Duration, it may be used in different Activities, and composed of other Equipment. The Construction entity space is based on a spatial view of a Construction entity, and it is composed of Construction entity parts seen as Enclosing elements.

The phenomenal property represented in the schema is intended to allow documentation of the intended phenomenal values of people active in the real situation. Such intended properties are e.g. feelings of comfort, beauty, and safety. These in turn are used as the basis for determining requirements on material properties of the built environment that may result in such feelings. This procedure is well known in design theory, see for example, The House of Quality Methodology (Cross 2000).

Documents resulting from a traditional architectural design process naturally display the built environment, while information about its use has to be

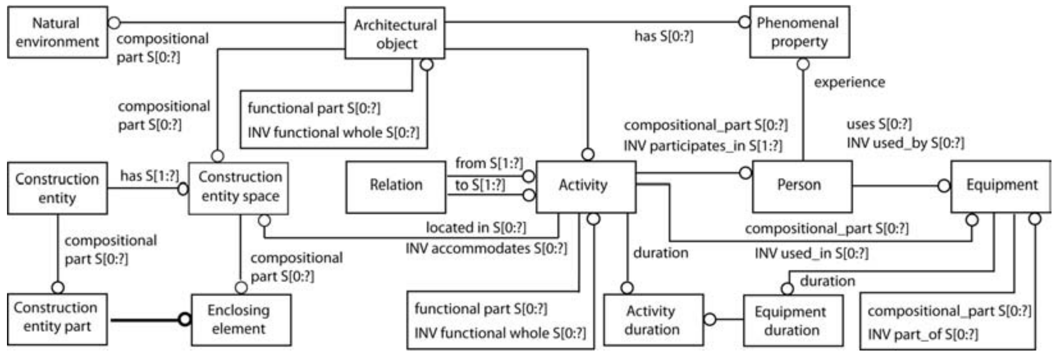

Figure 2. A tentative conceptual schema for an architectural object.

interpreted by the receivers of the documentation. Thus "one complete half of the 'ensemble' is completely missing" (Steadman 1979). By "ensemble" Steadman refers to the composite system of man and building in use. Through object oriented information management, it is now possible to represent also those concepts that in a paper based process traditionally are left to the reader's own interpretation. The concept of architectural object tries to capture the whole 'ensemble' seen as situations composed of both user and environment including its desired phenomenal properties.

3 CASE STUDY

3.1 *General*

The possibilities for rationalizing product design process and information management are considerable within industrialised house-building. Object oriented configuration and BIM-models could show noticeable synergy effects even in production and facility management. This case-study aims at studying modularisation in a company working with volume elements. These include spaces and could in a traditional design process by an architect be interpreted as "situations". The aim of the case is to explore whether a modularisation process could be based on architectural objects as well as on technical-functional objects.

3.2 *The company*

The studied company Open House Production AB is part of the Norwegian OBOS-group. The company is specialised in industrialised house-building, producing apartment buildings based on volume elements. During its 5 year operation about 1500 apartments have been finished in Oslo Norway and the Swedish Malmo region. Client has been another affiliate to the OBOS group, which has benefited the exploration of the concept.

3.3 *The concept*

3.3.1 *Modules and composed elements*

The Open House concept is based on lightweight steel and factory outfitted volume elements, inserted in a prefab steel frame on site. Other prefabricated parts are e.g. balconies, stairs, and installation shafts mounted on site. Long-time relations with sub-contractors and suppliers are contracted for parts not produced in-house. On-site production is limited, including foundation, finishing, service fittings and particular façade systems, reducing on-site activity to 2–3 months for a block of 40 apartments.

The system volume elements are named modules both as design objects and in its physical form. The system modularity is cc 3900 mm, leaving 3600 mm maximum room width. Length of modules is limited to house type or transport restrictions. Room height is set to 2600 mm. Prefab units, e.g. balconies, are handled as modular objects in the design process even if they are not volume elements. All modular units follow detailed type drawings of their compositional parts, e.g. wall elements with windows, doors and installations. These could also include prefabricated bathroom units or whole kitchen outfits from sub-contractors, with possible customer choice on a component level.

3.3.2 *Technical interface*

System details comprise the standardized interfaces between system modules and frame, its compositional parts, installations etc. as well as the interface to sub-contractors prefab completions. These predefined interfaces and limitations on system modules are considered being the system platform, still offering extensive freedom for architectural design in each system module as well as prefab unit.

3.3.3 *Product development*

Product development has mainly involved continuous multi-disciplinary system development with additional system details. Due to openness to customer requirements and architectural design the scope of the

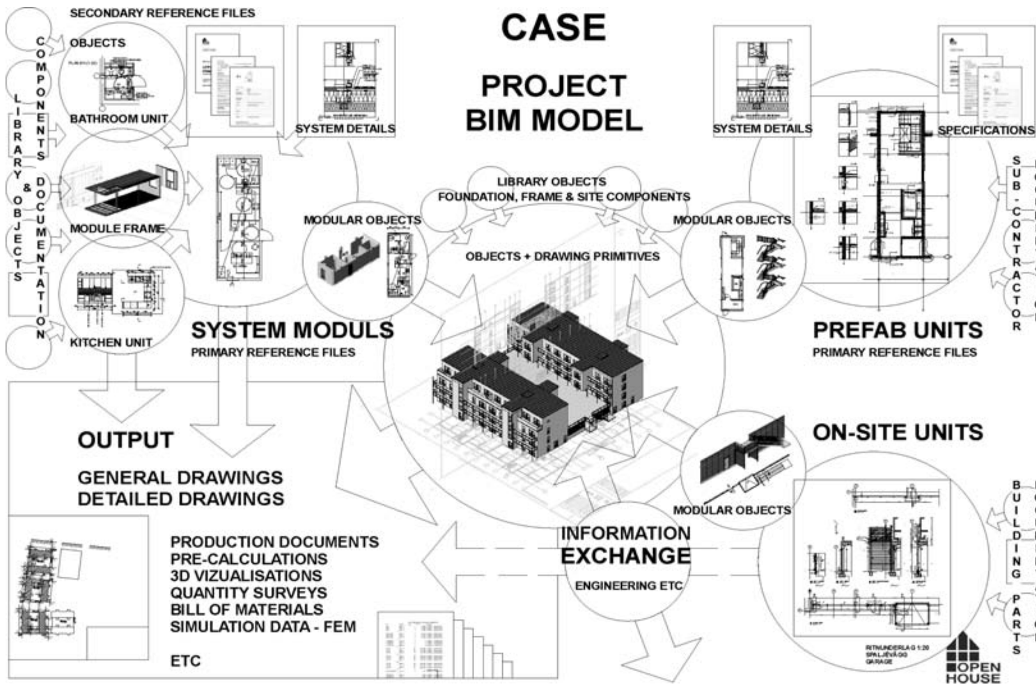

Figure 3. The company's project specific BIM model.

system platform has gradually been widened. A number of projects have also resulted in an extensive library with preferred design solutions for system modules, compositional parts and prefab units. These have been stored as reference files and objects in the evolved BIM environment, and are forming a product portfolio of configurable objects.

3.4 *Building project design*

3.4.1 *CAD-organisation*

The company's architects and engineers have a design and CAD coordinating role in a project and are responsible for the project's BIM model (see Fig. 3) developed in ArchiCad. The BIM-model is part of a project network, but information exchange is still based on dwg or pdf-format to external consultants through a common project server.

The BIM model acts as object database in the project, however also linking non-object oriented drawing files. From the model object, information for e.g. drawings, calculations, and 3D-vizualisation is presented. The model object's role for supporting configuration and coordination of the different project parts is vital for the design and production preparation process, even though the company does not use a PDM-system.

The BIM information is based on a number of objects represented in different product library and object reference files. In the project BIM model, these objects and additional drawing data are represented through hierarchically linked files corresponding to parts, assembly units, factory or prefab modules, and finally the project level.

General project information is received from the project model acting as the main BIM model, while factory drawings for volume elements are based on the project module files. Use of layers may collaterally limit the information carried on to superior levels and reduce file sizes.

3.4.2 *Brief development and customization*

In the building brief development phase the architect works with the client on a traditional building program, supplemented by 3D-sketches with objects in a preliminary project model. This pre-configuration in 3D is mostly using modular reference objects or mixing other reference objects, supporting the project modularisation as well as visualising the architecture to the customer. Customized design is this way offered to meet specific customer requirements, even though the compliance with the platform may sometimes be hard to predict for the architect and others.

3.4.3 *Project configuration*

In the systems design phase a more precise modularisation of the project model is done, turning it into a BIM model through configuration with reference objects, compiling it into a file structure and defining areas of responsibility. In general, existing reference objects, as general and high level as possible in the reference object file hierarchy should be preferred, reassuring that also structure, HVAC etc. will fit the general design and have proper system documentation. This also limits the need for external consultants in the particular project. By using predefined modular reference objects the architect can focus on the functional and spatial user perspective. But while the configuration methodology is not yet fully formalized the risk for sub-optimized design is obvious, as changes are called for in a non supported way. This often requires a third production document stage.

3.4.4 *Detailed design and production preparation*

All reference objects in the BIM model should have back-up information in its associated reference files. This, in order to support generation of production drawings and other documents. If new reference objects or combinations have been included this may however call for detailed interdisciplinary design work, often affecting system details as well. These drawings are mostly made in 2D. This could be if a façade material is altered or if new prefab balconies are introduced in the particular project. If this hasn't been called for long in advance such additions to the system platform may cause coordination problems between disciplines, resulting in increased costs and time delays.

4 ANALYSES

4.1 *Building design*

4.1.1 *Platform development vs building design*

The manufacturing industry distinguishes between product development and product styling through individual customer choice, so called configuration (Hvam 1999). Industrialised house-building has a clear process focus and applies the same strategy (Lessing 2006). Industrialisation still requires a reduced variation which is difficult for the building industry, since customer demands for flexibility has a strong tradition. The possibility for design versatility in a project is limited by the degrees of freedom inherent in its configurable parts.

4.1.2 *Building design and adaptability*

During the design phase both user activities and their relations to the building must be taken into account from a typological perspective. In apartment housing it is possible to identify building types according to the supporting structure and its floor plan versatility (Wallinder et al 1976, Wallinder 1982). The relation between user and building must also be determined in a long term perspective. This was the aim of the Structuralism theories developed by the Swedish National Board of Public Building defining the concepts of Building related and Activity related building elements (Ahrbom 1983), and the concepts Support and Infill developed by the Dutch SAR (Habraken et al 1974). This structural thinking corresponds to the idea of architectural objects, where user activities are central and should be enabled by the technical platform.

4.1.3 *The role of Cad-programs*

The development of object-oriented design with information stored in object models, has shown to be of importance not only to the design process and its production of drawings. The BIM model can also act as a project data-base and the object information handled according to needs formulated by the process stakeholders is of importance in the whole live-cycle of the building. Research and development in this area mainly concern standards for information processing and exchange between stake-holders in the process. However, only minor efforts have been made to understand the conceptual phase and how a BIM model originally is initiated and organized. In the design proposal stage, an object oriented systematic based on building elements demands a more detailed knowledge of the project than generally is at hand before a more detailed design is effectuated. As these initial steps address customer requirements and spatial-functional aspects, e.g. activities and aesthetics, they are furthermore hard to combine with the technical building element perspective.

In industrialised house-building where the technical systems are well defined a methodology with architectural objects would however be supportive not only in the brief development and conceptual design phase, but also for configuration in the proposal design phase, and also for handling user activity related information in the facility management phase. This could however invoke demands for specific software functionality in order to support the object systematic along with existing BIM object systematic. It may e.g. concern the representation of the BIM objects and their properties, and consequently how objects and files can be associated. Of certain interest are topics of object systematic as architectural objects relate to or include other objects and their properties, and may have user-defined parametric properties.

4.2 *Building design using architectural objects*

4.2.1 *Organisation*

A building, as designed, could be seen as composed of architectural objects, even an industrialised house-building platform could be formulated in terms of predefined architectural objects. These would serve as a basis for design configuration in the specific project.

Architectural objects could be organised in reference library files according to situation categories or level of detail. These situation levels might represent the block, the building, the apartment or room.

Except for the structuring principle with architectural objects, a similar file structure as in the case study would be aimed at in a design project. Repeated architectural objects within the same project should be using common reference files. This also applies to the hierarchies of linked project files. The matter of handling included objects and object properties in order to constitute the architectural objects will however need further investigation as to the mentioned software functionality.

4.2.2 *Properties of architectural objects*

The properties of activities and related spaces are fundamental to the properties of architectural objects. Space related entities include construction entity parts, these may however be included in different spaces. This means that a wall between two rooms or common service installations may appear in more than one architectural object.

Architectural objects may be joined or included in others; allowing mixed-use activities or hierarchies with situations on different levels. At least one activity object is present in an architectural object. This means for example that two architectural objects with the adjacent activities cooking and relaxing in an open floor plan joining kitchen-living room may form a new situation saving space, as such constituting a combined architectural object with its own properties.

Architectural objects may also in a systems view be excluding. In a hierarchy some construction entity objects might not affect the situations on that level and therefore be left out from the architectural object entities. As an example, the façade elements are of no interest for a cooking and dining experience but are relevant for the apartment living situation as such. This suggests that the designer should handle these issues in different contexts of architectural objects.

4.2.3 *Product development*

In a product development scenario, architectural objects would be related to the technical platform along with being flexible in ways meeting customer requirements. Properties linked to user activities and design experiences are central. Nevertheless the building is a combined system where architectural objects could be regarded as cornerstones for concurrent engineering. This, as most situations also involve serving systems and construction parts.

Independent architectural objects don't have to be static, but likely holds limited choice due to the industrialised context and the intended design. They could however be designed to allow optional choice in order to change the phenomenal properties or allow complementary activities. This could allow alternative placement of openings or doors in an inner wall. It could also mean styling, as materials and equipment offered in a kitchen. On the other hand architectural objects in a traditional building context could be the more flexible and allow parameterization.

4.2.4 *Programming and customization*

Relating to the case study, configuration with architectural objects could prove to be a similar but more organised way of handling customer requirements in relation to the platform. In a conceptual or programming phase architectural type objects for building types or apartment types as well as other preferred general architectural objects could be configured to form a preliminary project model and meet the general demands set out in the building program. The objects should all be a result of previous product development. The architectural apartment type objects would in that case hold some general activity properties as well as construction entity properties relevant to the type situation. These might serve as presumptions for later on included objects, e.g. space allowances for different activities in the apartment, or basic demands on materials that should affect the included detailed architectural objects. Preliminary BIM model data could at this stage be used for pre-calculations and be a result of experiential values set to the type objects.

4.2.5 *Project configuration*

In a detailed design phase a more firm configuration of the project BIM model would take place. Architectural objects are then successively arranged in the project hierarchy and "styled" according to the flexibility offered on a detailed architectural object level, see Fig. 4. For platforms describing standard type house solutions the flexibility might be more or less limited already on an apartment level, with only minor options concerning finishes etc. The Open House case with a more flexible platform would in this respect benefit more from the methodology, offering options for configuration on room level in situations as cooking, dining or sleeping constituting an apartment. Additional objects may be included but the scheme of architectural object should include most BIM-model objects, as parts of different situations.

5 CONCLUSIONS AND FUTURE DEVELOPMENT POSSIBILITIES

This study has introduced the concept of situation, described as a composite unit of human activity and environment having phenomenal values that support specific mind-sets and experiences during the activity.

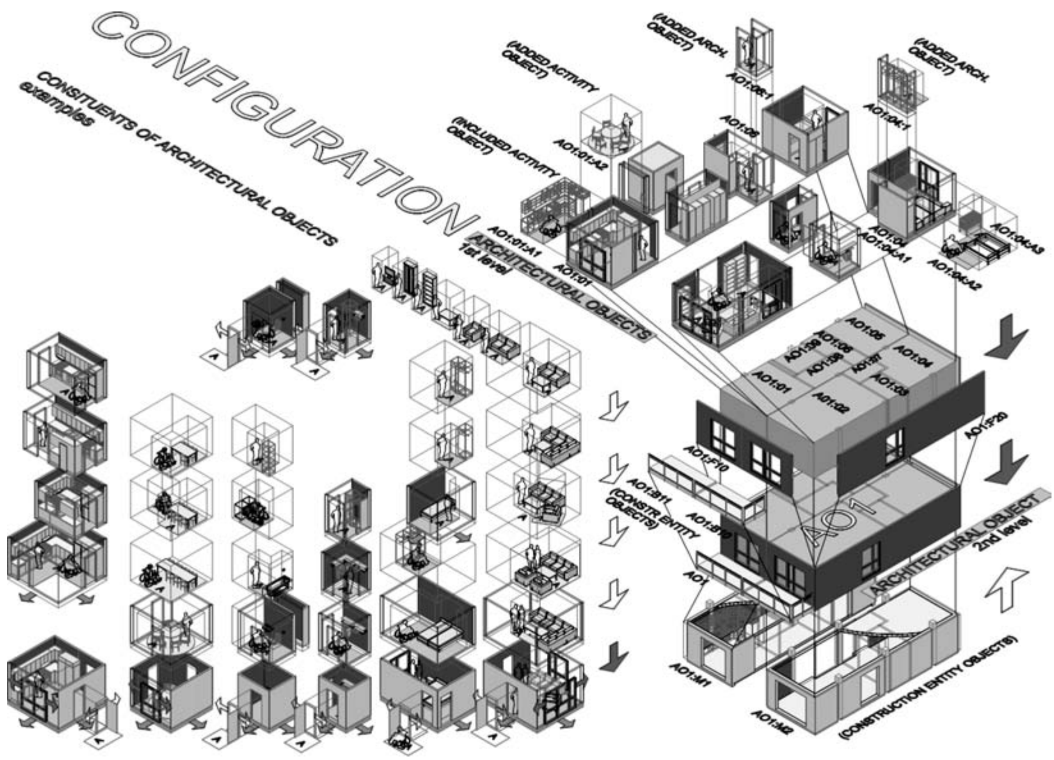

Figure 4. Product configuration.

A situation seen as a design unit is called "architectural object".

In a case study, we have analysed the design information structure of a company engaged in industrialised production of volume elements for house-building. The experience of the case project shows that configuration of volume elements need not take the technical system as a starting point. The volume elements are implicitly treated as architectural objects by the company architects during project design.

By formalising the concept architectural object and making it explicit, the related information concerning user activities and phenomenal properties, as required and designed, can be made accessible to all parties in the design, production and facilities management processes. The information can be used to gain experience of the building in use, for simulation, as input to brief development, and other analyses of interest.

In an industrialized building process including volume elements, architectural objects could be developed during the product development phase and applied during building project design as configurable design units.

If the project model and the volume type modules could be preconfigured as architectural objects, then deviations from the platform could be avoided already in the conceptual design stage. Choice options or parametric functions of the volume modules could limit the need for new and separate design solutions. However this requires that desired properties are formulated within a framework of architectural objects.

Design using architectural objects presupposes well defined activities and a technical platform with well defined building elements and resources. Concept development design however, puts other requirements on the Cad-software, including a high degree of flexibility with objects that manage geometry rather than building elements or activities.

Future research will investigate further possible application of the idea of architectural objects, specifically to support the architectural design process in industrialized house-building.

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Data, information and knowledge management, methods and tools

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Modelling the living building life-cycle

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ABSTRACT: Value orientation, industrialisation of building processes, cradle-to-cradle design and remanufacturing are currently important themes in building process innovation. In the context of the Living Building Concept, these themes have been analysed and integrated in the Living Building Concept framework. Furthermore, implications of these concepts for building information modelling and construction ICT have been explored. Parametric design technologies seem to become more important than ever. On the other hand, cradle-to-cradle design and remanufacturing seem to require a life-cycle modelling approach based on the life-cycle of materials and components, instead of the usual approach based on the building life cycle.

1 INTRODUCTION

1.1 *Building process innovation*

Some important strategic themes in current thinking on building process innovation are value orientation, industrialization of building processes, cradle-to-cradle design and remanufacturing. The building industry still has to put more emphasis on maximizing value for clients, end users and society, rather than on minimizing cost. Industrialization of building processes can potentially be helpful in achieving more value. But probably the greatest challenge for the building industry is the wide introduction for concepts such as cradle-to-cradle design and remanufacturing.

Integration of the strategic themes described above is an important part of the current Living Building Concept (LBC) (De Ridder 2006, De Ridder & Vrijhoef 2007). The Living Building Concept can be seen as a holistic approach for innovative building processes, based on various concepts from design theory, systems engineering, value engineering etc.

1.2 *Information technology*

As with almost all innovations in industry, information technology can act as an essential enabler for innovation. Emphasis on value means that design and engineering systems should support the concept of value. Regarding industrialisation, it is obvious that information technology can provide great support, using technologies such as parametric design and intelligent product libraries. With respect to cradle-to-cradle design and remanufacturing, things are less clear; maybe current ICT solutions are not fully adequate for the support of the latest insights in this area.

This paper is structured as follows. First the most important themes for building process innovation are discussed in the context of the Living Building Concept. Next, the implications of these themes for building information modelling and construction ICT are explored.

2 BUILDING PROCESS INNOVATION THEMES

This section discusses the most important themes for building process innovation in the context of the Living Building Concept.

2.1 *Value orientation and process dynamics*

A building can be seen as a solution for the housing of user processes. It creates an artificial environment that is optimal for these processes. It protects against influences from the external environment. This artificial environment that protects against external influences can be seen as the *value* of the building. Seemingly, this value was higher than the price for the client at the time of building. Also seemingly, the price was higher than the cost for the building supplier, otherwise he would not have built the building. These simple reasonings are described in the so-called Value-Price-Cost model, see Figure 1.

However, while current buildings are normally static, user requirements and environmental conditions change over time. Also most contracts and the current design and construction processes assume that user needs, once specified, never change. The consequence is that most buildings do not perform well after a while.

In other words, the dynamic nature of design and construction processes are not well supported

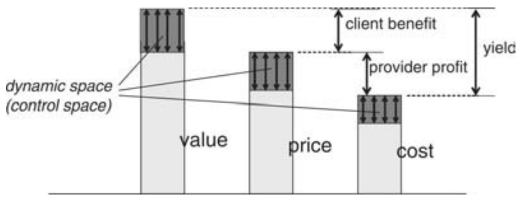

Figure 1. A price is agreed between client and provider between value and cost. The provider has an incentive to increase yield by cutting costs or by increasing client value.

by current work methods and tendering approaches. Therefore the Living Building Concept has proposed for example procedures for flexible use of tendering contracts.

But in order to support the dynamic nature of building requirements over the full life-cycle, it seems necessary to turn to a business concept that is currently not yet often used in building: Product Service Systems (PSS). Goedkoop et al. (1999) define a Product Service system as "a marketable set of products and services capable of jointly fulfilling a user's need". A key point of Product Service Systems is that companies in essence do not sell technical artefacts such as buildings, but *functions*. As a consequence, PSS agreements can be made for various periods of time. In case of long-term agreements it is well possible that many parts of the technical artefact are replaced, etc. The use of Product Service Systems in building is further discussed in Gielingh et al. (2007).

2.2 *Industrialisation – towards supplier-driven building processes*

In traditional building projects the project specification is fully determined by the client. Clients prepare a detailed design of what they want themselves, or hire a designer to do so. The supplier starts his work with a detailed design and works from there. This means that suppliers of traditional projects must be prepared to deal with all sorts of design proposals, and with all kinds of building methods. This traditional way of working can be called a "client-driven" building process.

In an industrial building process the roles of client and supplier are quite different. In such processes, the supplier normally has a building system consisting of a limited set of standard parts and connections and he will try to use this system as much as possible. The client in turn will only specify in global terms what he wants; the supplier develops the design and the client gives his approval. This way of working can be called a "supplier-driven" building process. It is comparable to a large extend with how the car industry works: client goes to supplier, supplier shows product catalogue, clients specifies in global terms, supplier develops a proposal, client gives his approval and production and delivery processes get started.

A "supplier-driven" industrial process has a number of advantages. First of all, it is possible to develop a proposal in a very short time by combining and assembling the standard parts of the existing building system. This can be done by using a parametric design system in which all standard parts and connections of the building system are stored, as well as design and construction knowledge associated with the parts and connections. Moreover, it is possible to gain insight in the consequences of the design proposal in a very short time, in terms of production and maintenance cost, but also in terms of environment impact etc. etc. Finally, a significant advantage is the possibility of an controlled industrial construction process, with potentially a much higher degree of precision, performance predictability and lower number of construction failures.

2.3 *Cradle-to-cradle design and remanufacturing*

A building is not only a fulfiller of e.g., a sheltering function, it is also a *materialized* solution for user needs that existed before it was made. Once the building is declared to be useless, it may be demolished. This attitude causes construction to be a large producer of waste. Not only the waste may be a problem, it causes also an exhaustion of natural resources.

Systems and components that are not any longer useful for one building may be re-installed in another building. And if systems or components cannot be re-used as such, the materials from which they are made can be disassembled and remanufactured for the production of new components or systems. The latter principle complies with the cradle-to-cradle concept such as described by McDonough and Braungart (2002).

The cradle-to-cradle principle implies that a design takes aspects such as reusability and disassembly into consideration. It has also implications for the use of materials and the way in which components are joined. An analysis of 20 Australian schools done by Ding (2007) revealed that the amount of energy needed to produce, maintain and demolish a school equals about 37 years of operational energy (heating, cooling, electricity). The selection of materials has therefore a major impact on the overall energy-consumption of a building. Materials such as cement and brick require very high temperatures in production; temperatures that may only be reached through the burning of hydrocarbons. Hence, the use of these materials contributes significantly to the global CO2 problem.

An LBC provider will be rewarded for the creation of value. Various kinds of value can be distinguished, such as user value, client value, social value and environmental value. User processes and the environment

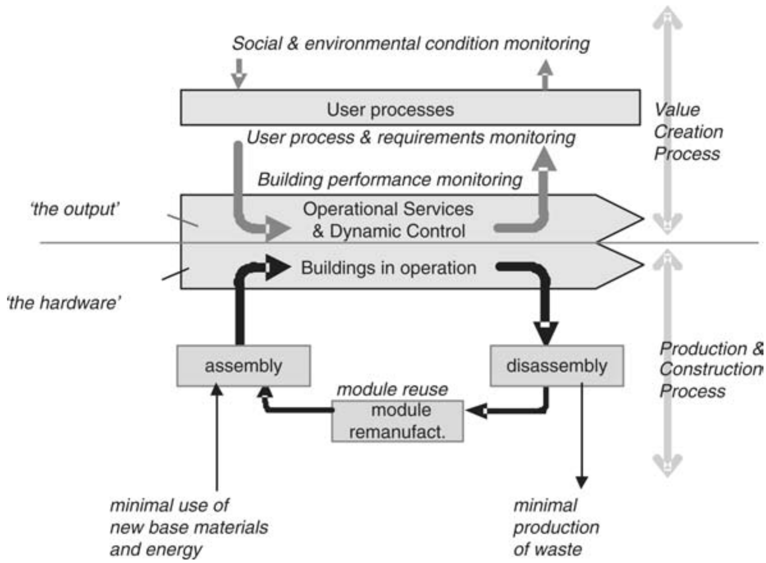

Figure 2. The process of a Living Building provider aims at reducing costs in the construction process and the increase of client value.

have to be monitored and measured. The provider, in consultation with the user(s), may take the initiative to modify the building so that more value can be created. During the modification of a building, user activities should continue, preferably undisturbed.

Where current, static buildings require high investments that have to be written off and are risky if user needs change considerably over time, the components and materials that constitute a living building have an extended lifetime that may be substantially longer than any individual building. Hence, the risks for investors decrease.

The other side of the medal is that the number of actions or operations per unit of material increases. In current construction practice, only the production, manufacturing and construction costs contribute to material costs. In living buildings, materials and components are manufactured, assembled, disassembled, remanufactured, and so on, perhaps many times during their (extended) lifetime. Manual work will therefore be costly. It may be more economical to automate these processes for Living Buildings than for traditional buildings.

The envisioned process of a Living Building product/service provider is sketched in Figure 2.

The left side of this diagram shows, from bottom to top, the construction process. The shown process starts with the production of assemblies out of raw materials, base materials and components.

In case changes of the building are needed during its operational life, the building will be partially disassembled and re-assembled. Removed modules may be re-used for assembly in the same or another building. If modules cannot be re-used as a whole, they will disassembled into components. Disassembly can be drastically simplified if fixtures of components and modules are designed for that purpose. Further, given the fact that vitalization may take place in a fully operational building, main disassembly and re-assembly should be designed such that ongoing activities in the building can continue with little or no disturbance.

3 IMPLICATION FOR BUILDING INFORMATION MODELLING AND CONSTRUCTION ICT

This section discusses the implications of the themes discussed above for information technology in construction.

Industry Foundation Classes (IFC) and Building Information Modelling (BIM) can be regarded as the current state of the art in information technology for construction. IFC and BIM are still not widely used in practice, but they are indeed widely known in the research and development community and often used as a basis for recent and current research, see for example Rebolj (2007).

Therefore IFC and BIM will be used as a reference for the discussion in this section.

Furthermore, a common model for building design processes shown in Figure 3 will be used. In this IDEF0-like model a design process is seen as a top down process with feedback-loops. Main activities are Design Building, Design Subsystems, Design Elements and Design Components. Main input (or control) is Building Requirements, main output is Building Design, etc, etc.

3.1 *Value orientation and process dynamics*

In order to support value orientation, building models should have model sections in which value(s) are modelled. To our knowledge, a lot of work still has to be done in this context. Value engineering and value management are established approaches, and models for these approaches do exist, but we are not aware of value models in the context of building information modelling.

What comes closest are models for building requirements. Figure 3 shows the relationship between Value, Specifications (of requirements), Design (solutions) and Cost, according to the Living Building Concept.

An important and influential model in this context has been the General AEC Reference Model (Gielingh 1988). In this model a Functional Unit/Technical Solution decomposition tree was used to model the relationship between requirements and solutions.

Over the years, alternative models for requirements and their relationship with design objects have been proposed. A recent example can be found in the SWOP project (Böhms et al. 2007) in which an attempt is made to develop an ontology for parametric engineering products, including product requirements, using Semantic Web methods and languages such as OWL.

The most difficult part of requirements modelling is the relationship between requirements and design objects on instance level. For example: how can I find the requirements for this door? The problem with this kind of questions is that the relationship between requirements and objects is not one-on-one.

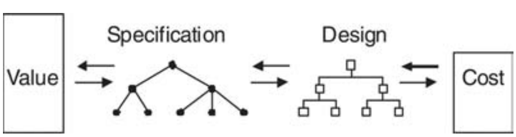

Figure 3. Design as a process to optimize the trade-off between value and cost.

The next question is whether current IFC and BIM can deal with process dynamics as described in the Living Building Concept. Is it possible to deal with contract changes, changes in user requirements and environmental conditions? These questions are closely related with the support of cradle-to-cradle design and remanufacturing, which will be discussed below in 3.3.

3.2 *Industrialisation of building processes*

As stated in 2.2, industrial building requires a supplier driven design process. The supplier has a building system with standard parts and connections and all kind of knowledge on these parts and connections. These standard parts are described parametrically and stored in intelligent part libraries. Information associated with these parts includes technical properties and characteristics, such as material, structural performance etc. Furthermore information is included on durability, maintenance aspects, as well as financial data.

What does this mean for the building design process? To a certain extend the common model as shown in Figure 4 can be maintained. But there will be some significant differences. First of all, design becomes mainly a *configuration* activity. The designing supplier uses the standard objects from his intelligent libraries and configures a design. An important part of this configuration process is the search-and-selection process of standard parts: a need for a function emerges, the associated requirements are analysed, part libraries are explored in search of standard parts that meet the requirements and one the standard parts that have been found, is selected for configuration. A process model for this “industrial”, configurable parametric design process is shown in Figure 5.

Part of this industrial design process is already supported by existing tools and technologies. Part libraries are already around for decades; parametric design systems are also around for many years. But a complete system for configurable design based on IFCs does not exist yet. Difficult parts are for example: the link between IFC-models and library structures, the link between library elements and functions and algoritms that can find matches, and the extension of product libraries with building knowledge of all kinds.

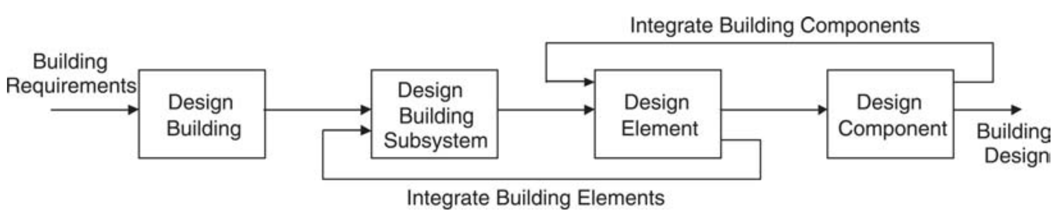

Figure 4. Common view of the building design process.

3.3 *Cradle-to-cradle design and remanufacturing*

The concepts of cradle-to-cradle design and remanufacturing probably have the biggest impact on the modelling and configuration management of buildings, systems and components, as well as on the modelling of materials, connections and (semi) automated processes. It requires the tracking and tracing of components that are part of large rotating pool, and which are installed in different buildings throughout their life. It may be economical to create an electronic market place for redundant components and materials. The concept requires also the modelling of user and environmental value- or cost-creating networks, as well as the social, economic and environmental impact of decisions for change. Moreover, the information and knowledge system that supports these processes should support the Living Building provider in a process of continuous improvement.

Current life-cycle building models similar to Figure 6 are far from adequate for the support of all these processes that can take place in the context of recycling and remanufacturing. First of all, the building-centered approach of most existing building life-cycle models must be abandoned. Components and assemblies are not only existing in the context of the building they are part of; their usage in a specific building is only of temporary nature. After a renovation, components can be replaced by other components, and the initial components can be re-used in another project, either without modification, or after modification, or even after a complete redesign leading to a different function or assembly in which the component resides.

In order to capture such component processes, it is much more worthwhile to invest in *component* life cycle models, see for example Figure 7.

Such component-centered life-cycle models could form the basis of information technology support for

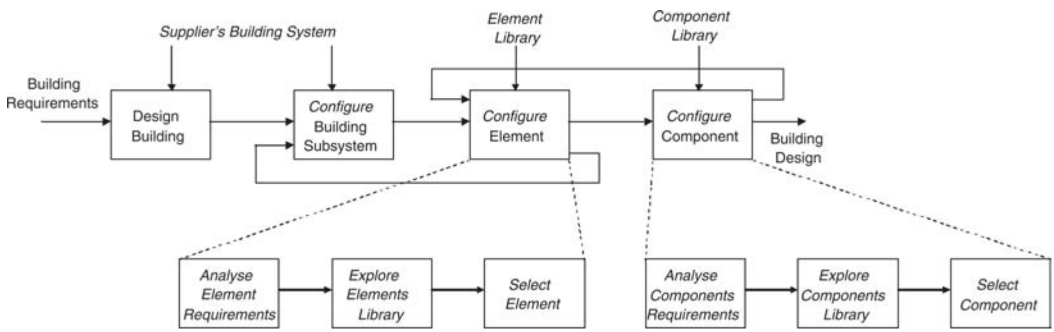

Figure 5. A model of building design as a configuration process. The supplier develops a building design by configuring elements and components from part libraries.

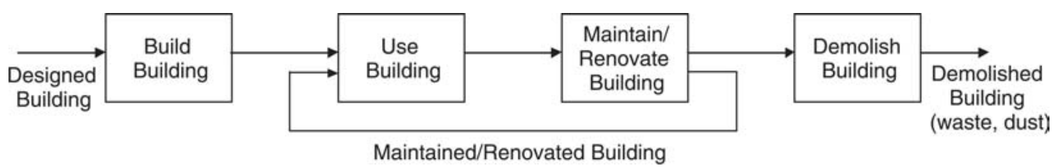

Figure 6. Common view of the life-cycle of buildings.

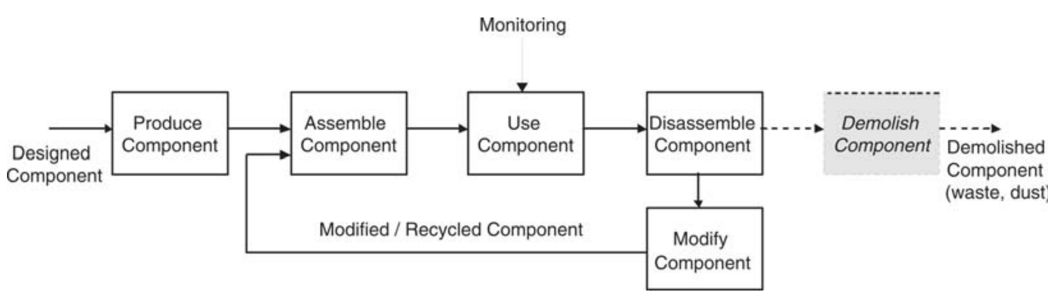

Figure 7. Life-cycle model of components in a Living Building Process, in which recycling of components is maximized and waste production is minimized; the model can be extended with re-design of recycled components.

a new management approach for building, facilities management and real estate management, in which cradle-to-cradle and remanufacturing principles are full acknowledged.

An important part of the model is the monitoring function of components in use: there must be some kind of warning mechanism that gives a sign when components need to be replaced. This implies that ultimately all components of the building should be monitored; this means a challenge for domotics and sensor technology, but developments in this area are going rapidly, so this is probably not a serious bottleneck.

Furthermore, full implementation of such component-based models for "the living building life cycle", will require technological progress in the area of so-called intelligent building objects: building objects with built-in chips in which all kind of object information is stored, for example information on the object's history, or the original intent of it. Of course it should be possible to extract this information in order to make the right decision in a re-use consideration.

4 CONCLUSIONS AND FURTHER WORK

In this paper the concepts of value orientation, industrialisation of building processes, cradle-to-cradle design and remanufacturing have been analysed in the context of the Living Building Concept. Furthermore, the implications of these concepts for building information modelling and construction ICT have been explored.

A first conclusion from this is that parametric design technologies will probably become more important than ever. But more importantly, cradle-to-cradle design and remanufacturing seem to require another life-cycle modelling approach than the usual one based life-cycle of the building, namely an approach based on the life-cycles of all involved materials and components.

The work presented here is in an early stage of research and a lot of work remains to be done. In the paper a number of tasks to be done are given. In the area of industrial building the greatest challenges are in the integration of already existing technologies such as parametric design systems, standard part libraries and IFC. In the area of cradle-to-cradle design and remanufacturing much more fundamental work needs to be done: elaboration of building component life cycle models, integration of these models in building management systems and integration of these technologies with new hardware developments such as monitoring sensor technology and intelligent building objects.

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Virtual testing laboratory for FIDE compliant software

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ABSTRACT: The use of data models in the construction sector in order to facilitate the exchange and integration of the information among the different stakeholders who participate in the processes of projecting and constructing buildings has become too common. Software developers who implement these data models in their applications have to guarantee the quality of their developments taking into account the compatibility with data models and the capacity to exchange information. To ensure the quality of the software is necessary to check the developments by means of automatic and objective procedures. Virtual Test Laboratory offers online test software procedures, test data and tools, and statistical software qualification procedures to evaluate the quality of the FIDE compliant software.

1 INTRODUCTION

The exchange and integration of the information among the different stakeholders who participate in the processes of projecting and constructing public and private buildings and infrastructures (architects, engineers, constructors, ...) are critical points that the construction industry must approach for being able to benefit from the enormous potential of productivity increase than the application of the Information & Communications Technology do provide.

In this line, a data model has been developed both regional and national level, FIDE. The FIDE initiative has established a reference framework in Spain for the integration of the information in the construction process. It allows the compatibility of the existing software applications in the market, and has been considered a model or standard system of common data exchange within the sector in the Business-2-Administration arena.

FIDE data model is public and open. It focuses on the scope of the Spanish National Technical Building Code (TBC). The TBC is the normative framework that establishes the safety and habitability requirements of buildings set out in the building Act (LOE), (CTE, 2008). In addition, FIDE model has been developed taking into account the possible relations with the most internationally extended standards and data models, like the IFC from the IAI. (building SMART alliance, 2008).

The use of data models in the building sector is too common and, therefore, it is necessary to have at an automatic and objective mechanism to evaluate the quality of software that implements these data models.

Virtual Testing Laboratory aims to check FIDE compliant software, both commercial and promoted by Public Authorities, in order to guarantee its quality. Software developers will have an objective tool to check their applications and, thus, to guarantee the quality of the software applications from the standpoint of compatibility and capacity to exchange information.

Virtual Testing Laboratory will offer online test software procedures (Abstract Test Suites), test data and tools (Test Suites) and statistical procedures for software qualification to evaluate in an objective way the progress and quality of the FIDE compliant software.

Virtual Testing Laboratory will provide the evaluation of different FIDE scopes in an independent way. This will facilitate both the model integration and the software evaluation.

This project follows, in a different knowledge scope, the objectives and experiences put into practice in the international area in ISO TC184 SC4 for the software test compatible with STEP (Standard for the Exchange of Product Data) ISO 10303, (2008).

This development is very significant in the FIDE initiative because the technology will provide the automatism of the analysis and certification process to the Public Administration, like the application of the quality or accessibility rules, or other parameters included in the Technical Building Code. Through these automated processes, technician responsible of the analysis of the building projects will have at very useful tools that will facilitate certification works.

The aim of this paper is to describe how Virtual Laboratory will be developed. For this reason, the paper is structured as follows: Section 2 describes the main objective of the virtual testing laboratory. Section 3 shows the FIDE initiative, the methodology used in the FIDE model development, including management and organization issues. In this section, model management and software quality check methodology will be described. Section 4 describes the virtual testing laboratory, the different technologies used in its development and the different stages in the total work. Finally, Section 5 summarizes the benefits that will be obtained by the different stakeholders by using the virtual laboratory.

2 OBJECTIVES

The main aim of Virtual Testing Laboratory is to provide software developers a tool to verify their developments and guarantee their quality, from the point of view of compatibility and capacity to exchange information.

Thus, Virtual Testing Laboratory is closely related to FIDE initiative. It is an essential tool to achieve the development goals of the initiative, since it will facilitate the development of FIDE compliant applications.

FIDE initiative arises as a result of the need for a common reference framework in the Spanish construction sector for information exchange. Public Administration is one of the most benefit agents, because it has to receive a large amount of documentation associated with a building project. Each of these documents has to be processed manually through repetitive procedures. The use of digital formats will allow to process information automatically.

On the other hand, the use of a common data format provides important benefits to the rest of the stakeholders, since it is possible to reuse the information, improving the efficiency of the construction processes.

The use of a widely extended and accepted will be the key to the development of software applications. These tools will take profit from a common language that will facilitate the reuse of the information, the data processing automation, etc. However, data model implementations have requirements to be fulfilled to guarantee their quality. Virtual Testing Laboratory is the tool that will allow checking the compatibility between software applications and FIDE data model.

In more detail, the objectives of the FIDE initiative can be enumerated as follows:

- To provide software developer a tool to check the compatibility between their applications and FIDE data model in an objective way.
- To facilitate the development of automated analysis and project certification processes by Public Administrations and competent organisms.
- To foster the construction sector development by improving the efficiency of the current ways of working.
- To facilitate the interoperability between the sector stakeholders independently of the computer applications used for different purposes.

3 FIDE INITIATIVE

In this section, some fundamental concepts of FIDE initiative will be described. These concepts will help to understand the necessity of the Virtual Testing Laboratory. The section is divided in two parts. First, FIDE data model will be described, explaining in detail both the development methodology as technical issues. Then, the proposed management methodology to guarantee the compatibility between FIDE data model and FIDE compliant software applications will be explained in detail. Besides, the need for the existence of the virtual laboratory will be described.

3.1 *Development methodology*

A mayor concern in the FIDE data model development is the quality assurance. For this reason, the model must be understandable for the developers in charge of its implementation. This applies mainly to software application developers but also to work groups dedicated to make extensions of the FIDE model in some specific area. To this end, some basic norms related to naming and structure of the model will have to be followed and a complete and well-done documentation of the model is essential.

The methodology includes the description of the steps to be followed in the development of new models or sub-models:

- Identification of the sub-model field. The developer group must identify the field of study where they are going to work, that sets the framework where the concepts to be modeled are fitted.
- Process model definition. A process model must be defined, preferably using IDEFO representation, which includes the processes under study in the modeling exercise. The process model must include the exchanged documents as well as the participating agents. On the other hand there also exists the possibility for the developers to identify de processes on a reference standard process model instead of developing a new one.
- Integration within the global model. A study must be performed in order to identify which parts of the global model are going to be affected by the sub-model to be developed.
- Model development. Finally, the work group will proceed to the actual model development. To that

end, they will develop the parts not included in the global FIDE model. Subsequently, they will proceed to the integration of the sub-model within the global FIDE model.

3.2 *Technical issues*

FIDE data model has been developed with XML technologies. The reasons for adopting these technologies are varied. First, XML meta-language is the de facto standard for data exchange in the network. This will facilitate the relation between Administration and the industry. Besides, there are a lot of available software tools to work with XML, a lot of tools for manipulating XML files and a lot of development tools such as programming libraries and SDKs (Software Development Kits). This does easier the adoption in the industry of XML structures. Finally, there exists a set of XML-based technologies to manipulate XML files: XSL, XSLT, XPath and XQuery, etc, which will facilitate the FIDE files transformation.

Moreover, the most extended international standards in this sector, ISO STEP and IAI IFC, evolve or already support XML.

3.3 *Developments*

FIDE model has specially been developed in the area of quality management in the construction sector. In the case of Spanish situation, quality control procedures are mainly driven by de Administration (control book, quality profile, building book, etc.). Safety and habitability requirements of buildings set out in the TBC have also been analyzed. Thus, FIDE data model includes all the information, both structural as administrative, related with a building project.

Basic data model structure is defined as follows:

– Each entity represents a real world concept. These elements are represented by means of XML schemas and have a set of fields for identification, description, location and specific characteristics and relations with other elements.
– There is a mandatory element called *DescriptorEdificacion*. It contains general data of the construction project and structural information about the building.
– There are several fields called *Collections* where similar elements will be put together to establish conceptual groups (building elements, materials, agents . . .)
– The whole structure is a layered structure:
  – Each layer contains the entities that several entities from an upper layer do use. This way the model avoids duplicity of re-used elements in the model.
  – The lower level is called kernel. It contains the most basic and re-used elements.

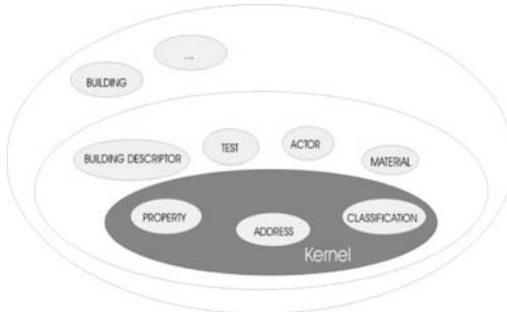

Figure 1. FIDE general structure. The structure is layered.

3.4 *Management methodology*

Management structures of FIDE initiative have an informal profile, since it is a young initiative. In the medium term, management structures will be organized as the following elements and responsibilities:

– Steering Committee. This is composed by representatives of Public Administrations, both national and regional administrations. The Steering Committee is in charge of the following works:
  – To set the main strategic lines of the FIDE initiative.
  – To make the decisions about activity foundation.
  – To approve FIDE projects.
– Technical Committee. This is composed by qualified technicians from different organizations than take part in FIDE initiative. The Technical Committee is in charge of the following works:
  – To define and control the FIDE quality management and its implementations.
  – To coordinate the different work groups.
  – To define the technological environment where FIDE activities will be developed.
  – To monitor the development methodology and tools.
  – To develop the infrastructure and common information resources (website, mechanism for information exchange . . .).
  – To represent FIDE initiative before other technical agencies, like IAI, OASIS, CEN, and ISO . . .
– Work Groups. They can be made up ad-hoc for solving specific objectives within the model. They should make an agreement with the Technical Committee to decide the suitability of their objectives and their work plan within the FIDE model long-term objectives.

3.5 *Test tools necessity*

Since the TBC publication, software applications related to the new normative have been developed. These applications could implement FIDE data model as a data exchange format.

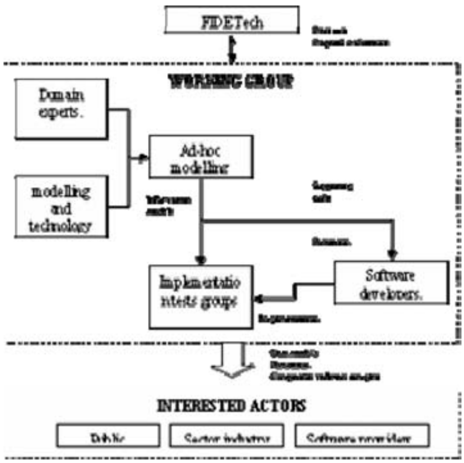

Figure 2. Work groups structure.

At national level, some of these applications are LIDER, software to calculate energetic demand in buildings, and CALENER, software to calculate energetic consume and obtain an energetic qualification.

At regional level, related with Housing and Buildings Quality Plan, there are some actions undertaken by the Comunidad Valenciana to the promotion and advancement of quality in the building sector. Thus, software applications, such as Quality Profile, have been developed. This tool characterizes the buildings according to quality requirements set by the European Directive and included in the building Act (LOE) and in the regional Act for the Building Quality Promotions (LOFCE), providing a distinctive. Other software applications are Building Book, which includes the administrative and legal documentation, technical documentation and documentation concerning the use and maintenance of the building.

FIDE implementation in these software applications involves that it is necessary to guarantee their quality and compatibility with FIDE format. Thus, it will be possible to avoid the possibility that the converters to or from FIDE format have technical failures. These failures could generate mistakes in the translation, so the interoperability wouldn't be guaranteed. Virtual Testing Laboratory will allow the evaluation of different FIDE implementation in an automatic and totally objective way, guaranteeing the quality of different tools.

4 VIRTUAL TESTING LABORATORY

4.1 *Technology issues*

Virtual Laboratory project will apply rules-based systems, aimed at integrating expert systems into systems of compatibility analysis (or Conformance Test mechanisms).

This project is based in techniques used in CORENET project, in Singapore, in which rules-based systems were implemented for Conformance test analysis in building projects. Virtual laboratory project will lay the foundations for FIDE projects can be analysed in a semi-automatic way by decision supporting systems that will help to government employees in their task of reviewing projects.

In the software engineering scope, a test set or a validation set, called *abstract test suite*, is a test collection that must be passed by a software application. In this way, the compliance with specification and requirements for which was designed is guaranteed.

An abstract test suite consists of abstract test cases. An abstract test case is a complete and independent specification of an action required to achieve a specific objective in a test.

Abstract test cases normally describe test that software applications must pass and are related with specific functionalities that these applications implement (in this case, import /export FIDE format).

FIDE data model have a so broad scope and it is necessary, besides to guarantee/prove the generation of a FIDE syntactically compliant file, to generate test oriented to data semantics, data consistency and, finally, compliance of rules that are applicable to building projects.

A set of test cases is based-rules system. The representation of the knowledge in a set of rules allows the integration of an expert system in a *conformance tester* (software application that performs the test). These rules can have associated some parameters, like confidence and uncertainty factors.

From the point of view of the data model schema, there is a development area started with Schematron project performed by the NIST (National Institute of Standards and Technology from EEUU) (Schematron, 2008). This project offers software development resources to improve the analysis based on grammars using patterns. Schematron is part of an ISO standard (DSDL: Document Schema Description Languages) (ISO/IEC 19757 – DSDL, 2008) and allows to work with multiple XML validation languages.

4.2 *Virtual Laboratory scope*

Virtual Laboratory project aims to develop a tool kit that allows:

- Software developers to prove their FIDE implementations and obtain feedback about the quality of these implementations.
- Responsible for developing new knowledge areas within FIDE data model to establish new test sets related with these areas. These test sets guarantee the

compatibility of software applications that implement these knowledge areas, and the homogeneous semantic interpretation of data model in a new area.
– Responsible for FIDE initiative to check the compatibility of FIDE developments. In this way, it is possible to avoid expensive verification procedures and test that would need a lot of resources.

In short, project consists of developing:

– A Virtual Testing Laboratory that will be accessible by FIDE developers and will implement necessary tests to check if the developments are FIDE compliant.
– A methodology that allows developers of new knowledge areas to define, necessary case test, to specify them in an homogeneous way, to design them, to implement them and, finally, to attach them to the virtual laboratory.
– A pilot test that check both the virtual laboratory and the specification and development methodology of new use cases. Pilot test will be aimed to two different scopes: building quality and energetic qualification of buildings, both already included in the FIDE initiative. Moreover, software that implements these scopes will be checked.

Conformance Test Laboratories are tool kits that allow checking if a software application conforms to some specifications or the compliance level that reaches.

In the case of FIDE, because it is a XML data model, it is possible to establish a priori different basic tests to verify the quality of the implementations. In a XML schema, it is possible to describe syntactical rules in any XML instance by means of XML parsers that allow discovering errors in the XML document associated to a schema.

As well as the valid syntax of a file, there are other checks that it is necessary to do, particularly when these XML FIDE files have to be shared and filled in by different software applications.

Main problem is data loss. Data loss may take place when an existent file is imported by a software application and, after saving it again, it has lost some of original data.

Given the complexity of FIDE data model, another significant problem has been taken into account. It is possible that references between elements are incorrect. So, although a FIDE file was syntactically correct, the interpretation of file contents may be wrong (for example, a material identifier referring to the building element definition).

These examples will be basic tests in the Virtual Laboratory. However, apart from these general basic tests, it is necessary to consider some specific tests related with the different knowledge scopes included in FIDE data model.

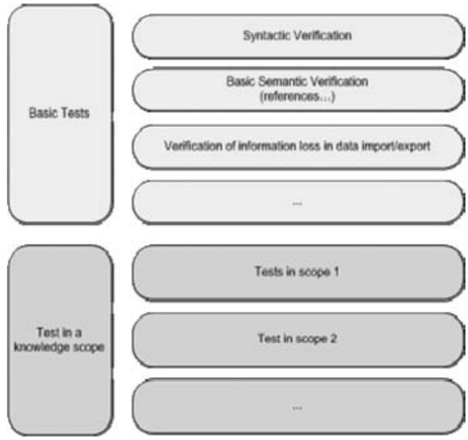

Figure 3. Levels of verification according to software profiles.

Each knowledge scope includes its own needs and restrictions. Normally, software applications aimed to a specific knowledge area. Therefore, a software application needs to pass semantic tests related with its scope. In this way, software tools will have both syntactic as semantic compatibility with requirements of its own scope. For example, a software application aimed to quality control in Spain has to pass a test suite related with concepts in the building quality area.

To achieve these certification levels, different Technologies will be used. XML parsers that check a file syntactically are the most basic tests. In the remaining cases, more advanced technologies will be needed. These technologies will constitute a small expert system for each FIDE area to check. Technologies like Schematron or JESS (Java Expert System Shell) will allow the introduction of rules and axioms related with data contained into FIDE files.

Thus, it will be necessary to define different application profiles. Each application must pass a test according to its profile and test results will describe test requirements that application has passed and the compliance level with these requirements.

Finally, different tests can be added to virtual laboratory system. Tests have to carry out specific requirements included in the specification and test cases development guide. Each test is modular and reusable. In this way, these tests can be linked in complex test sets, or as pre-requisites of other tests. To do this, it will be necessary to use service oriented technologies (SOA).

4.3 *Work plan*

4.3.1 *Requirements analysis and specification*

The aim of this task is to define the functional specification of the tool that implement the test system for

FIDE compliant software applications (Virtual Laboratory). Firstly, previous internationally initiative will be analyzed especially ISO initiative, as well as tools for the compliance with the specifications.

Then, it will be necessary to develop different use cases, especially basic tests such as syntactic compliance, data loss, etc.

Virtual Laboratory should be a flexible and configurable environment, but it should be robust and allow increasing the number of tests. Finally, taking into account previous performances, functional specification will be defined.

4.3.2 *Pilot cases specification*

The aim of this task is to define de specification of test cases, that is, FIDE knowledge scopes that will be developed. Firstly, it is necessary to choose test cases, taking into account the current state of FIDE data model, the functional scopes that it includes (building quality, energetic efficiency, etc) and different applications that are able to use FIDE data format.

4.3.3 *Test environment design*

Once analysis of requirements and functional specifications tasks have been carried out, it is necessary to search and check possible suitable technologies and tools.

If it is possible, open source tools will be used. Technologies like Schematron or JESS (Java Expert System Shell) (JESS 2008), will be tools that should be linked with different developments. In this way, these tools will be used to specify contents of use cases chosen in a standardized way.

When tools have been selected, it is necessary to specify the application architecture. The basic points of this architecture will be based on Java Technologies, although a SOA environment will be offer by means of web services. This will allow other extern applications to use some functionalities of the Virtual Laboratory, and also the reuse of basic tests inside of complex test sets.

4.3.4 *Pilot test cases design and development*

The aim of this task is to develop the technical specification and necessary tools to perform pilot test cases and their incorporation to the Virtual Laboratory.

4.3.5 *Test environment development*

In this task, web platform that will contain Virtual Laboratory will be developed. This process will consist on the implementation of security mechanisms and user's identification, basic application test mechanisms, addition and execution mechanism of test cases in the Virtual Laboratory, etc.

Since use cases are defined externally to Virtual Laboratory, it is necessary to develop a mechanism to do result reports, flexible and defined by each test case in the Virtual Laboratory.

Virtual Laboratory modules will be accessible through a service-oriented architecture. This architecture will enable the use of modules as web services so that a broader test can be composed without having to define more basic tests. Software applications can access the Virtual Laboratory and may use different use cases.

5 BENEFITS

As it has already been mentioned, one of main problems of different stakeholders in building sector is the exchange and the integration of information among them. Because of this, efficiency levels in the building sector are very low. It is estimated that 30% of the costs of the lack of interoperability are due to the lack of standardization.

The use of a common and open data model allow the information management, control and processing in a more secure and easy way. This involves a drastic reduction in resources used by all actors, particularly by Public Administration.

The usage of a common and open data model will allow a drastic reduction in the use of resources by all the involved agents. This specially applies for the Public Administrations in their task of the management and control of the information, documents and files generated during the construction process. Using a data model avoids duplicating the common information in a building Project. This reduces the risk of mistakes and reduces the cost in time, which increases the efficiency of agents.

Moreover, the usage of an open and public data model allows different users (included Public Administrations) to choose their systems and not to depend on a particular system to guarantee the interoperability.

To extend the usage of a data model among the different actors in the building sector, it is necessary that software developers integrate it so that they are consistent with the model.

Virtual Testing Laboratory for FIDE compliant applications will allow developers to check their software and guarantee the software quality to the user. An agreement evaluation of the software compatibility means the obtaining a quality certificate.

6 CONCLUSIONS

Following are shown the most important conclusions:

- The use and implementation of data models involve the need for mechanisms to evaluate the quality of the model integration in software applications.
- Automatic testing mechanisms will facilitate the tasks of the technicians who have to evaluate the fulfilment of model requirements.

– Test tool architecture should be modular. In this way, it will be possible to use modules as web services in order to compose a broader test without having to define more tests.
– Test cases will be developed as web services so that other applications can use functionalities in an automatic way and reuse of basic tests inside of complex test sets.
– The quality guarantee of an application will be shown with a certificate and a quality label. This will provide the application with added value.

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Project information management: Proposed framework and comparison with the 1COBIT framework

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ABSTRACT: Emerging Information and Communication Technologies offer major improvements to the practice of civil and building engineering. Techniques such as Building Information Modelling may substantially alter project design and management practices. Yet these systems are complex and are not easily adopted into current practice. This suggests that current work in civil and building information and communications technologies cannot achieve its full potential unless we also develop our practices for managing information on projects. Project Information Management is the practice of managing a civil or building engineering project's information systems, including its bodies of information, its information and communication technologies, and its related work practices. We contend that Project Information Management should be developed into a more formal and explicit sub-discipline of project management. In this paper, we will present suggestions for an overall framework for Project Information Management. We also describe the existing COBIT international standard for IT management and discuss its applicability for project information management for civil and building engineering.

1 INTRODUCTION

Information and communication have always been important to architecture, engineering, and construction (AEC) projects, yet approaches for managing information have generally been informal and ad-hoc. While information and communication technologies (ICT) have the potential to provide huge rewards to project organizations, they often fail to do so. The value can only be realized with effective management processes. We have argued that the AEC industry would benefit from the development of project information management (PIM) as a well-understood and formalized sub-discipline of project management. Not only would this benefit projects in general, but it seems to be a necessary pre-condition to the successful implementation of more complex emerging ICT such as Building Information Models (BIM).

PIM could be considered as very analogous to functions such as safety, risk, or quality, which have also been long recognized as important to project management in the construction industry; yet over time, these areas have evolved from loosely-defined project management objectives to distinct sub-disciplines with well-understood requirements, procedures, bodies of knowledge, and roles within the overall project management process. The same can be said for information management. For example, one chapter of the Project Management Institute's Project Management Body of Knowledge (PMI 2000) defines a communications planning framework, yet this falls well short of a comprehensive approach to PIM. Information management seems far behind the areas of cost, schedule, scope, safety, risk, or quality as a well defined and understood sub-discipline of project management.

In our work, however, we have focused on the development of information management practices as they relate to the management of individual construction projects in the context of emerging ICT. Our methodology involves condensing a wide range of PIM-related work and ideas into an overall proposed framework for PIM. With this framework as a starting point, we then intend to carry out case studies to determine best practices and to refine the framework, followed by implementation of the framework on pilot projects. We are currently in the early stages of this endeavor, focusing on the preliminary framework and initial case studies.

Previously (Froese, 2004-2006c), we have argued the need for PIM, drawn analogies to quality management and ISO 9001, presented an initial conceptual framework, and discussed organizational issues and the role of a Project Information Officer. In this paper, we discuss an existing international standard for IT management, the COBIT Framework (IT Governance Institute 2007), and its applicability to PIM for AEC projects. We also describe our proposed PIM framework.

2 THE COBIT FRAMEWORK

COBIT (Control Objectives for Information and related Technology), produced by the ICT Governance Institute, and provides a framework for best practices in the governance and management of IT.

The COBIT framework presents best practices for the management of IT by defining a process model that identifies a broad range of activities that make up IT management. This process model is well-integrated with a range of corporate governance issues. For example, the management processes flow from IT objectives which, in turn, are derived from business objectives. The processes are mapped to the main types of IT resources that must be efficiently utilized and to the responsible corporate roles. The process descriptions include detailed control objectives and assessment parameters to enable strong governance of the IT management processes.

2.1 *The key characteristics of COBIT*

The COBIT framework has been developed to satisfy four key characteristics of being business-focused, process-oriented, controls-based and measurement-driven.

The business-focus characteristic is achieved largely by using business goals to drive the IT objectives and processes. For example, COBIT envisions a process whereby Enterprise strategy leads to business objectives, which in turn lead to both general business criteria for the IT systems (effectiveness, efficiency, confidentiality, integrity, availability, compliance, and reliability), as well as specific IT system objectives. These IT system objectives, then, drive the definition of the IT management processes required to meet the objectives. The framework also takes the perspective that the business requirements for IT are satisfied by the overall enterprise architecture for IT, which is comprised of the IT resources of applications, information, infrastructure, and people.

The process-orientation characteristics is central to COBIT since the framework defines a series of 34 management processes organized into four domain groups. These are described later in this paper.

The controls-based characteristic is significant within COBIT because it emphasizes that the IT management processes require corresponding controls. Controls are the governance or oversight procedures that provide assurance that the business objectives are achieved and undesirable outcomes are avoided. COBIT supports control by defining control objectives for each of the 34 processes, as well as a set of generic control objectives that apply to all processes and to all IT applications.

Finally, COBIT satisfies the characteristic of being measurement-driven since it provides performance goals and metrics for all of the processes. These metrics are given in the form of maturity models.

2.2 *The COBIT template for process descriptions*

Having described the above characteristics in some detail, the COBIT framework goes on to the describe each of the 34 management processes, following a particular template for each. For each management process, the template describes the process, including brief statements of the key IT/process goals and measurement metrics, and maps it to several of the issues introduced in the previous discussion–the business criteria for IT, the four domain groups, the IT Governance processes, and the IT resources.

The template then itemizes and describes the detailed control objectives. This is followed by management guidelines, consisting of linkages to all other processes that provide inputs or require outputs of this process, a chart of the associated roles and responsibilities, and a chart of the goals and metrics at the IT, process and activities levels.

Finally, the template defines six layers of a maturity model for each process.

2.3 *The COBIT processes*

Although a description and discussion of each COBIT process is beyond the scope of this paper, the titles are listed as follows:

Plan and Organize
- PO1 Define a strategic IT plan.
- PO2 Define the information architecture.
- PO3 Determine technological direction.
- PO4 Define the IT processes, organization and relationships.
- PO5 Manage the IT investment.
- PO6 Communicate management aims and direction.
- PO7 Manage IT human resources.
- PO8 Manage quality.
- PO9 Assess and manage IT risks.
- PO10 Manage projects.

Acquire and Implement
- AI1 Identify automated solutions.
- AI2 Acquire and maintain application software.
- AI3 Acquire and maintain technology infrastructure.
- AI4 Enable operation and use.
- AI5 Procure IT resources.
- AI6 Manage changes.
- AI7 Install and accredit solutions and changes.

Deliver and Support
- DS1 Define and manage service levels.
- DS2 Manage third-party services.
- DS3 Manage performance and capacity.

DS4 Ensure continuous service.
DS5 Ensure systems security.
DS6 Identify and allocate costs.
DS7 Educate and train users.
DS8 Manage service desk and incidents.
DS9 Manage the configuration.
DS10 Manage problems.
DS11 Manage data.
DS12 Manage the physical environment.
DS13 Manage operations.

Monitor and Evaluate
ME1 Monitor and evaluate IT performance.
ME2 Monitor and evaluate internal control.
ME3 Ensure compliance with external requirements.
ME4 Provide IT governance.

2.4 *Applicability of COBIT for project information management.*

The COBIT framework provides a very comprehensive approach to IT management that captures a significant body of best practice. As we will describe below, we have incorporated aspects of COBIT into our proposed approach to project information management. For several reasons, however, we are not convinced that COBIT itself provides a solution to the project information management challenge. First, COBIT itself claims that it is "strongly focused more on control, less on execution" (IT Governance Institute 2007, page 5). Control is indeed of great importance and a focus on control would be useful at the project level, but the focus of our interest (and probably a more pressing need) is on providing guidance and formalism at the level of operational management. Second, the organization context of AEC projects is that people from many different (and often quite small) companies come together to collaborate as a virtual organization over a relatively short project life cycle (from a few months to a few years). Project IT systems may frequently need to tie into corporate systems from multiple companies. This short and dynamic context precludes some of the levels of planning and control that are suggested by the COBIT framework. Third, the fact that project information management for AEC projects is a much more specific application domain than the generic business focus of COBIT creates the opportunity to provide a framework that is somewhat more specific and targeted than the COBIT framework.

3 THE PIM FRAMEWORK

As a sub-component of project management, PIM is the management of the information systems on a project to meet the relevant objectives. We suggest this definition of PIM because it emphasizes four core elements:

- The Project: PIM activities are entirely grounded in the context of the AEC project. This is in contrast to much IT that is more enterprise-focused than project-focused.
- The Information Systems: In PIM, the things being managed are the information systems used on the project.
- The Management Process: PIM is a process carried out by those responsible for managing the project's information systems.
- Objectives: The purpose, goals, and success criteria of PIM are defined by various objectives that arise at the enterprise, project and information system levels.

This core framework consisting of 4 basic dimensions is in contrast to the COBIT framework which might be described as a single basic dimension (management processes), but with these processes heavily integrated to many different issues (such as objectives). The two approaches are not substantially different in the way that they identify and integrate management processes, information system resources, and objectives, but we believe that the approach should also be closely linked to the defined project activities, which is not readily apparent in the COBIT model.

Each of these core elements will be addressed in the following sections.

3.1 *The AEC project*

PIM manages the information systems for an AEC project. The focus on the project is significant for two reasons. First, it defines the business scope for PIM. Although information systems will exist and will be managed at the enterprise level, corporate information management is not sufficient to ensure that project information systems are adequately addressed. This is because the project information systems are so tightly tied into the project management practices that the management of those systems must come (at least in part) from within the project management team itself. Furthermore, projects are carried out by stakeholders from many different companies, thus project information management must be responsive to this "virtual organization" focus.

Second PIM must look to the project itself to define what information systems need to be created and managed. We suggest a "tasks/transactions/ integration" approach in which PIM considers each project task in the work breakdown structure, each transaction involving information flows between tasks, and significant integration issues to arrive at a list of information system requirements.

This dimension does not appear to be explicitly captured in the COBIT approach.

3.2 *Information systems*

Although it is something of an over simplification, we suggest that it is convenient to approach PIM as “processes” acting on “things”, where the information systems are the things and the PIM are the processes. The practice of PIM, therefore, requires detailed knowledge of the information systems used on the project. These information systems can be defined largely in terms of the key information resources: information, applications, communications, information infrastructure, and people. These correspond to the IT resources defined in COBIT. In a framework focused specifically on PIM for AEC, these could likely be decomposed into much more specific information system elements.

The linkage between these information systems elements and the project elements is evident when considering the issue of identifying the required information systems (introduced in the previous section). A review of the project tasks will identify the key computer applications required to support the work, while a review of the project transactions will identify the key project communications required. In analyzing each of these, the key information input/output requirements will be assessed. Having identified application, communication and information requirements (along with integration requirements), the infrastructure and personnel resources required to support these information systems can be identified.

Although it is reasonable to consider all of the information resources used to support an AEC project as the project’s information system, there will typically be several critical applications that require significant management effort, but that may be largely independent from each other. It is useful to view these as the major information sub-systems.

A detailed knowledge of the technical aspects of the project information systems is critical for PIM, but it is outside of the scope of this paper.

3.3 *Information management*

Information management defines the processes used to manage the information system resources. At the highest level, this PIM involves the generic management processes of planning, executing, and monitoring the results.

However, we can define the required processes in substantially more detail. This is an area where COBIT provides good detail that could likely be adapted to PIM. In future work, we intend to suggest which COBIT process are best suited for AEC PIM. One of the ways in which COBIT can be modified is to define the level at which its various components are best applied: at the level of company, at the level of individual projects, at the level of the project subsystems, etc. (see the discussion of the scope hierarchy later in this paper).

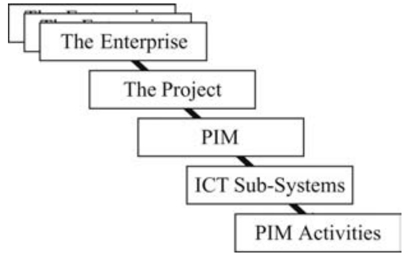

Figure 1. The scope hierarchy for PIM.

3.4 *Objectives*

The PIM management processes are objective-driven. That is, a set of explicit objectives is used to identify the required information systems, to guide the PIM process, and to assess the results. The COBIT framework provides detailed information on appropriate ICT objectives, which should be extended for application to PIM. Like the management processes, different objectives are associated with different levels: some arise from the business goals at the enterprise level, some correspond to the project objectives at the overall project level, others are specific to individual ICT sub-systems, etc. These levels are discussed further in the following section.

4 THE PIM SCOPE HIERARCHY

4.1 *Enterprise, project, subsystems, processes.*

The previous section presented a brief overview of the PIM framework in terms of its four core elements. Beyond this simple introduction, there are a great many issues relating to PIM that can be addressed, such as the details of the management processes to be carried out, technical aspects of the project ICT systems, organizational issues for PIM, etc. In this paper, however, we address just two of the many issues: the PIM scope hierarchy and delivering PIM.

PIM is not practiced in isolation, rather it is integral with corporate business practices, with the overall project management, etc. The previous overview of PIM mentioned a few situations where different levels must be considered. We describe these levels as making up the scope hierarchy for PIM, as illustrated in Figure 1.

The highest level is that of the enterprise. PIM is tightly linked to corporate information management, both because the key project ICT is often inherited from the ICT systems in use within the corporation, and if good corporate information management practices exist, then these will directly spawn much of the PIM practices. There are significant benefits from having project ICT and PIM derived from the corporate level–it involves short lead times where time is always of the essence, users will often be familiar with the systems and practices, and it helps to ensure that the project level will integrate will with the corporate level. As we have mentioned, however, corporate level ICT and ICT governance does not fulfill the need for project level systems and management. A significant additional complication is that the project is made up of key stakeholders from many different companies, who must collaborate closely throughout the project. Thus, project ICT and PIM will often need to combine and blend systems and practices from more than one corporation, which will inevitably involve compromise and a certain amount of customization for each project.

The next level is that of the project. PIM should be considered to be an integral part of the overall project management. As ICT is becoming increasingly central to the design and management processes, the management of these systems must increasingly become a key line function within project management (just as cost and time management are), rather than a supporting staff function that is not considered to be central to the management of the project.

Below the project level is the project information management which addresses the project's information system as a whole and the project-wide PIM practices. Much of the management activity relating to policies, planning, resources, etc. takes place at this level.

Although all of the project's ICT resources make up the overall information system, we have mentioned that there are frequently several key, largely independent information sub-systems (for example, the project may make extensive use of a CAD system, a project management/scheduling system, and a web-based collaboration system, with only minimal interfaces between these major systems). Each of these will have specific management requirements, so some PIM activity will take place at the level of these ICT sub-systems.

Finally, the lowest level of PIM scope is where a specific ICT-related activity must take place that warrants PIM attention. Examples might include a procedure for using a specific software application for a specific task (e.g., using 4D CAD for construction planning), or a procedure for a particular data transaction (e.g., submitting progress claims electronically). Such procedures are considered to be individual PIM activities, and can be planned and documents in PIM methods statements. Much of the actual PIM-related activity occurs at this level.

5 CONCLUSIONS

We argue that emerging ICT cannot achieve its full potential to improve the AEC industry unless we develop a more formal understanding of Project Information Management (PIM) as a sub-discipline of project management. COBIT is an existing international standards that provides a basis for information management. We describe COBIT and its potential applicability to PIM. Drawing upon COBIT and several other sources, we have suggested an overall framework for PIM made up of four core elements: The project, the project's information systems, the management processes, and the relevant objectives. We have discussed a scope hierarchy for PIM.

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Evaluating the integrative function of ERP systems used within the construction industry

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ABSTRACT: A research effort for enabling the integrated use of information within a construction enterprise needs to deal with diverse issues such as information centrality, information and service level integration strategies, and building up successful enterprise architecture within the organisation. Enterprise Resource Planning (ERP) systems have emerged to achieve the capability to plan and integrate enterprise-wide information resources. However, ERP implementations in the construction industry have so far yielded more failures than successes due to inconsistencies between the process definitions of standard ERP applications and the processes construction industry. Thus, the integrative function of ERP systems can not be fully realised by the construction industry. This paper presents the findings of a study that aimed to determine the role of ERP systems used in the construction industry in enabling integration, specifically at data and information levels. In parallel with its aim, a framework for formalising the integration in data and information levels and a metric for measuring the integrative function of ERP systems in enabling data and information level integration are defined as a part of this research. The applicability of the proposed framework and metric is validated with four case studies in the final stage of the research.

1 INTRODUCTION

The nature of the construction industry is very much fragmented where each discipline in the industry has evolved independently with their own unique terminology, technology and way of expressing and communicating information. This structure of the industry has caused many problems with regard to information sharing and exchange. Current research in Construction Informatics is mainly focused on enabling interoperability and integrated model based engineering throughout the life cycle of the facility. In contrast, enabling the integrated use of information within a construction enterprise needs to deal with diverse issues related to information centrality, data, application and service level integration strategies, and building up a successful enterprise architecture within the organisation.

In recent years, the need to gain competitive advantage in the globalised industry has forced organisations to work in platforms, where operations can be executed fast and business information can be recorded and accessed efficiently. As a result of the requirements for information integration and operational efficiency, Enterprise Resource Planning (ERP) systems have emerged to achieve the capability to plan and integrate enterprise-wide resources (Yang et al., 2007). Having been influenced by the successes of the production industries, the construction industry has also conducted utilization trials of ERP systems. However, many of these trials have caused ERP systems to just remain integrating the back office corporate functions such as financial management, etc. ERP implementations have so far yielded more failures than successes in large construction firms, which in main has been caused by the disparity and inconsistency between the process definitions in the standard ERP applications and business processes of the construction industry (Voordijk et al., 2003). As a result of this failure rate, the integrative function of ERP systems can not be fully recognised within the industry.

The aim of this study was to determine the role of ERP systems used in the construction industry in enabling integration, specifically at data and information levels. The objectives of the research included defining metrics for measuring the integrative function of ERP systems in enabling data and information level integration, and validating these metrics with real-life case studies.

The research started with a literature review on methods for enabling integration in data, application and web service levels. In the following stage of the research, a framework was developed for formalising the data and information level integration in the implementation of the ERP systems. In the next stage of the research, a matrix is proposed – ERP Data and Information Level Integration Maturity Matrix (EMM) – as a metric that was used to evaluate the maturity in data and information level integration achieved by the organisation during an ERP implementation.

Finally, 4 case studies were conducted with Large Scale Enterprises (LSEs) in the industry in order to validate the applicability of the defined metric (EMM) and evaluate the level of maturity in terms of data and information level integration using the proposed metric.

2 ENTERPRISE RESOURCE PLANNING SYSTEMS

The key idea behind the use of ERP Systems is to plan and integrate enterprise-wide resources. As also mentioned by (Kumar et al., 2003; Yang et al., 2007), having implemented an ERP system an organisation becomes capable of providing different levels of information about diverse range of intra-organisational processes to its employees and project partners by integrating the information from multiple resources.

The literature in the area points out numerous different definitions about ERP such as Davenport, 1998; Bingi et al., 1999; Klaus et al., 2000; Markus and Tanis, 2000; Grant, 2000; Mullane, 2001; Abdinnour-Helm et al., 2003; Voordijk et al., 2003; Shi and Halpin, 2003; and Yang et al., 2007. In light of the definitions provided in the literature, an ERP System can be described as:

"An information system, which integrates processes in different units and departments of an enterprise (i.e. finance, accounting, HR, production, marketing, procurement, logistics, trade, inventory management, warehouse management, CRM, project management etc.) within – a single information acquiring/processing platform and a unique data infrastructure – which acts as a unique information resource that provides most up-to-date information for the processes."

An ERP system is formed by the integration of a set of software components (modules), which (usually) use a shared database, containing multiple data models defined according to the needs of different departments. The database of an ERP system can be reached from various different end-user interfaces. This unique architecture is one of the definitive features of the ERP system. The literature in the field suggests that the main barrier to implementing an ERP system is the high implementation and maintenance costs (charged by the system vendors). Another barrier to the implementation is the need for a change in the process which emerges throughout the implementation of the system. As explained in Bocij et al., (1999), the process change required through the ERP implementation process will often bring improvements in efficiency to everyday tasks. However, the new way of working and the newly implemented system can also bring disruption. Thus, the implementation process carries substantial risk for the routine processes in the organisation. Success of an ERP system generally depends on an organisations' ability to cope with the process re-engineering issue. Processes which are not aligned with the new way of working are behind much of those failure stories (Bocij et al.,1999).Two methods can be used to overcome this process related barrier. The first one is re-engineering of existing processes and the second one is the adaptation of software in such a way that eliminates the need for process change. However, for the second situation, the ERP project may lose its focus and trajectory, and the organisation will start to interpret the project as a regular software development effort rather than facilitating business process improvement enabled through effective use of ICTs.

2.1 *ERP systems and the construction industry*

The project-oriented working style and business processes have caused problems for construction industry organisations when implementing ERP systems, which were mainly designed and developed for production line industries (Kuruoglu, 2002).

Construction projects consist of numerous -project related- and unique processes in tendering, cost estimating, contractor/sub-contractor management, project finance, manpower management, management of 3rd party and outsourced services, facility management, health and safety management, ergonomics management which in the main are not covered by most of the standard ERP systems. In fact,the literature review in the field identified several studies investigating the use (and role of) ERP systems within the construction industry. For example, Mullane (2001) introduces ERP systems and provides a general model of today's ERP architectures in the AEC industry. Shi & Halpin (2003) underlined the importance of the establishment of the basic theory for developing Construction Enterprise Resource Planning Systems (CERP). Voordjik et al. (2003) investigated the factors that lead to the success or failure of ERP in large construction enterprises in the Netherlands. Ahmed et al. (2003) looked at the implementation status of ERP systems in contractor firms. Barthope et al., (2004) examined the current ERP awareness in the UK construction industry. The authors also investigated the potential for integrating the data of supply chain management using an ERP system. Vlachopoulov and Manthou (2006) described the necessary steps for the implementation of an ERP system for enterprises working in the Greek construction industry and finally Yang et al., (2007) conducted a case study investigating an ERP implementation of a local construction company in Taiwan.

3 AN INTRODCTION TO SYSTEMS INTEGRATION

3.1 *Integration levels and methods*

Integration can be defined as a strategic approach for binding many information systems together in order to support their ability to exchange information and leverage processes in real time (Linthicum, 2003).

The literature review in the area of software systems integration (Linthicum, 2003; Erl, 2004; Ruggiero, 2005; Imhoff, 2005;Hohpe and Woolf, 2003) highlighted two main integration approaches:

- Integration at Data and Information Levels
- Service and Application Level integration

Integration at Data and Information Levels (Information Integration) allows data and information to move between source and target systems without involving its application logic (Linthicum, 2003; Erl, 2004).

Methods for Information Integration can be classified in 4 different categories as:

1. Data and information exchange methods: In exchange methods, the data is exchanged between different applications and/or databases (without modifications in the logical, physical model of the data). Exchange methods include physical file exchange, transfer of information from a physical file to a database and vice versa, and transfer of information between the databases (also known as data replication)
2. Data and Information sharing methods: In sharing methods a central data set is stored in physical files or databases and shared among various parties. Sharing methods include sharing of physical files (through application programming interfaces -APIs-) and sharing of data in a central or federated database
3. Data transformation methods: In transformation methods the data is transformed from a specific data type or model into a different data type or model. Data transformation can be conducted between files, databases, from file to the database and vice versa. The main difference between the data exchange and transformation is that the logical and/or physical model of the data changes during the transformation process, whereas in contrast the data models remain unchanged in a data exchange.
4. Relate-Search-Retrieve methods: In these methods the integration is achieved through the reasoning (i.e. at the knowledge level) by using ontologies/semantic web, data mining and other methods of -knowledge discovery in databases-. In order to implement these methods some meta-level tasks (such as data identification, building up data catalogues, ontologies and topic maps, and a meta-level data model) need to be completed.

In contrast to the Integration at Data and Information Levels, Service and Application Level integration involves the use of application logic, remote procedure invocation, distributed objects and web services. Service and Application Level integration methods can be classified under the following categories:

- Remote Procedure Invocation (RMI)
- Messaging
- Distributed Interoperable Objects / Object Request Brokers
- Web Services (RMI + Messaging + Web)
- Integration at portal level (not abbreviated)
- *References between parentheses:* (Fig. 1), (Figs 2-4, 6, 8a, b) (abbreviated)
- USA / UK / Netherlands / the Netherlands *instead of* U.S.A. / U.K. / The Netherlands

4 A CONCEPTUAL FRAMEWORK FOR DATA AND INFORMATION LEVEL INTEGRATION

The literature in the field presents various methods for systems integration at the information, application and service levels. The framework that will be summarised in this section is developed in light of the methods established, for formalizing the integration activities at the data and information level. The framework can also be regarded as a methodology for achieving the systems integration by integrating the information resources.

4.1 *Data and information level integration framework*

The proposed framework includes three main stages to achieve the targeted data and information level integration. The following explains these stages and the tasks needed to be completed in each stage.

Stage 1→ Meta Level Activities

The first stage of a data and information level integration effort is conducting the meta-level activities. These activities play a role in identifying and categorising the data sources of an enterprise and building a reliable data repository for the organisation. Meta-level activities start with *data identification* activities which include the identification and the location of the required files and databases, the structure of the data models in the databases, the ownership information, and reverse engineering of logical and physical data models. The *data identification* stage also includes the analysis of existing data dictionaries to highlight the reasons for the existence of some data models, the security parameters, and the format of the data. The developers need to begin thinking about data integrity issues during this stage. The following step of the meta-level integration activities is building up a data catalogue. As mentioned in Linthicum (2003), the data catalogue can be defined as a comprehensive enterprise-wide data dictionary (i.e. a data dictionary covering all existing data dictionaries in the enterprise). The data catalogue will include information on processes, communication mechanisms, along with traditional metadata such as format of the data, names of the attributes and description of tables and attributes.

The data catalogue will act as the dictionary of data and processes. The catalogue will help in overcoming the data redundancies in existing data models. The next step in the approach is building up an enterprise level metadata model. The metadata model provides the definitions for the data models, the relation between the data models and interactions between the data models and the application (logic) components. As explained by Linthicum (2003), the metadata model will be used as a reference point for not only the data, but also rules and logic that apply to data. The metadata repository built for enabling Data and Information Level Integration will also provide the basis for Service and Application Level Integration. In order to facilitate domain and process oriented reasoning and implement the Relate-Search-Retrieve methods, the final step of this stage is developing domain and process oriented ontology and taxonomies. A semantic web can be built upon these structures in a later stage of the integration.

Stage 2→Data Movement Frequency

After conducting the meta-level activities the second stage of a data and information level integration effort will be determining the data movement frequency. The data movement would be between files, between databases, and between files and databases.

Depending on the needs of the process and the integrated applications, the data movement frequency will vary depending on the ratio of batch processing and real time processing systems in the enterprise.

The data movement frequency needs to be determined based on the business processes as a part of an information integration effort (i.e. before the design of the integration components). The integration components will then be developed to enable the transformation and movement of data between different data stores.

Stage 3→ Selection of the Integration Methods

The last and most important stage of a data and information level integration effort is determining an integration method for each specific data component that would be integrated. The integration method can be one of exchange, sharing or transformation methods, and in addition, relate-search-retrieve methods can be used when some kind of analysis and reasoning is required in the integration process.

Table 1. ERP Data and Information Level Integration Maturity Matrix.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
Data Movement Frequency							
Batch Processing				Real Time Processing			
%				%			
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.		Shared File		F→F		Sem. Web.	
F→DB		Shared DB		F→DB		Knowledge Disc. DB	
DB→F		Federated DB		DB→F		Other	
DB→DB				DB→DB			

4.2 ERP Data and Information Level Integration Maturity Matrix (EMM)

In parallel with the aim and objectives of the research, the ERP Data and Information Level Integration Maturity Matrix (EMM) is developed as a metric that can be used to evaluate the maturity in data and information level integration achieved by the organisation during an ERP implementation.

The matrix is composed of three main parts that corresponds to the three main activities in the Data and Information Level Integration Framework (Meta Level Activities, Data Movement Frequency, Integration Method). The first part aims to discover if meta-level activities have been completed before/during the ERP implementation process and the types of the meta-level activities that are completed.

The second section is developed with the intention of determining the percentage of batch and real time data processing activities. The third section investigates which of the data and information integration methods are used throughout the ERP implementation process.

Although the diversity in the meta-level activities is directly proportional to enterprise-wide (and process oriented) integration requirements, this diversity can also provide an indication on the maturity of the (data and information level) integration in the enterprise. Despite of the fact that it is very difficult to derive quantitative figures from the matrix to measure the maturity of the integration, the information provided by the matrix can help in understanding the extent of the integration implemented within the enterprise. Thus, the matrix (and the diversity of the methods used in the integration) might provide an empirical evidence for understanding the level of maturity in the integration process.

The following section summarises four case studies that were conducted within LSEs in the construction industry in order to, i) validate the applicability of the defined metric (EMM) and ii) evaluate the level of maturity in terms of data and information level integration using the proposed metric.

5 CASE STUDIES

The case studies explained in this section are conducted with two of the leading contractors of Turkey – MNG Group and Sinpas Company Group, and two leading system integrators in Turkey – Tepum Technology (the ERP solution partner of Microsoft) and Oracle Turkey.

The cases studies were conducted through face to face (semi-structured) interviews, where the participants from the construction industry explained their experiences in developing/aligning ERP systems for their enterprise, and the participants from the system integrators explained their experience in their implementations and the capabilities of their system for enabling data and information level integration. The information gathered throughout the case studies from both the construction industry professionals and from the software integrators allowed the maturity analysis to be conducted from different perspectives.

5.1 *Case Studies: Construction Enterprises*

5.1.1 *Sinpas Company Group*

Sinpas Company Group was founded in 1974 and specialises in constructing residential and commercial properties. The company group started implementing IFS ERP System a few years ago to manage its business and financial activities. The system implemented in the Sinpas Company Group consists of an Oracle Database (as the main data repository) and eight modules.

The modules implemented in Sinpas are Procurement, Planning, Progress Reporting, Finance, Juristic, Human Resources (HR) and Maintenance.

The Planning module runs integrated with the time and cost management solution. The Progress Reporting module, which runs integrated with Planning and Procurement modules, was developed and implemented as result of a joint effort by IFS and Sinpas. The HR module implemented in Sinpas is integrated with a HR web site.

As the first step of the implementation effort, the data identification had been completed as a result of a comprehensive data analysis activity. Following this, a Data Dictionary and Catalogue was created. This dictionary is still being updated as new data models are introduced to the working system. In fact, the semi-structured interviews identified that an enterprise-wide Meta Level Data Model was not developed prior to the implementation.

The ratio of real-time update of the data to the updates by batch processing found as 1:1. Users working at different construction sites have an access to all the data in the system in real-time over Virtual Private Networks (VPN).

In terms of the integration approach in data and information level, the implemented system (IFS ERP) makes use of most of the data exchange methods (such as file exchange, and exchange of information between files and databases). All modules of the system are capable of exchanging information by file exchange and exchange of information from database to files. Information exchange from file to database is only used by the HR and Planning modules. In fact the data replication method is not used as the overall system is working on a single central data repository. The data exchange methods are mostly used when a need appears for exporting the data out of the system.

The file sharing method is used by Finance, Planning and Procurement modules of the system. These modules have the ability to access the shared files produced by one of these three modules. The IFS system is mainly using the data sharing approach, whereby a centrally shared data repository is accessible from all the modules and the modules communicate with the central data store over a VPN for security reasons.

The file transformation method is used for importing data from an off-the-shelf accounting application to the IFS ERP system. The off-the-shelf accounting application was still in use as the implementation of the Financial module (of the ERP system) was still not completed (at the time of the case study).The other transformation method used in the system is file to database transformation. This method is used for acquiring information for the HR module from the files. The transformation is accomplished by an in-house developed software component. The research results pointed out that database to file and database to database (or in database) transformation methods are not used in this implementation.

Topic maps were used in the system design and implementation and in fact the implementation effort did not cover the development of an ontology/taxonomy and an infrastructure for supporting the semantic web. The Knowledge Discovery methods

Table 2. EMM for Sinpas Company Group.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
+		+		+			
Data Movement Frequency							
Batch Processing				Real Time Processing			
50%				50%			
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve . Methods	
F. Exch.	+	Shared File	+	F→F	+	Sem. Web.	
F→DB	+	Shared DB	+	F→DB	+	Knowledge Disc. DB	+
DB→F	+	Federated DB		DB→F		Other	+
DB→DB				DB→DB			

Table 3. EMM for MNG Group.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
+		+					
Data Movement Frequency							
Batch Processing				Real Time Processing			
10%				90%			
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.	+	Shared File		F→F		Sem. Web.	
F→DB	+	Shared DB	+	F→DB		Knowledge Disc. DB	+
DB→F	+	Federated DB		DB→F	+	Other	
DB→DB				DB→DB			

(such as Data Mining) are applied when some distinctive reports are required for cost and progress estimation activities and process monitoring. The ERP Data and Information Level Integration Maturity Matrix for Sinpas can be found in Table 2.

5.1.2 *MNG Group*

The MNG Group is founded as a result of the alliance of two companies Gunal and Mapa which were founded in late 1970s. These two companies specialise in the construction of, tourism buildings, prestigious residential, commercial and civic buildings, and the urban infrastructure. The MNG Group today owns over 43 companies, most of which are operating in the global construction industry. The group also owns an airline (MNG Airlines), one of the largest logistics companies of the country (MNG Kargo) along with several tourism companies.

After several unsuccessful trials of (off the shelf) ERP implementations (and the tailoring of off-the-shelf systems for the needs of the enterprise), the group decided to form a team for developing an ERP system using its own human resources. The MNG Group have been in the implementation process of their in-house ERP system (namely Parametrik) for some years, and they view ERP implementation and maintenance process as a never ending development/maintenance lifecycle.

The participants of the case studies from MNG Group indicated that the Parametrik system is based on interoperable technologies. The main module of the ERP system (Parametrik) consists of Accounting, HR, Inventory and Finance modules. Additional modules include Logistics Management (LM), Point of Sales (POS) Management, and Bidding Management.

Within MNG Group, Data Identification and Cataloguing have been initiated prior to the implementation of the ERP system. In fact, a comprehensive Meta Data Model was not built.

The data updates within the system modules are being made in real-time, with the exception of the LM module for which the data is updated with batch processing. The amount of data generated and used by the LM module is high, thus in order to maintain the systems' performance, the data of the module is transferred into the main database once or twice a day through batch processing.

In terms of the integration methods, all modules make use of file exchange method. File to database and database to file exchange methods are used only within the LM Module. The data replication method is not used as the ERP system works over a single data repository.

All system modules access data through a shared central data repository. As the modules have direct access to the database, file to file and file to database transformations are not required. In fact the data residing in the database can be transformed into several different file formats depending on the data requirements of the external applications.

The Knowledge Discovery methods are used when generating reports for tactical and strategic management levels. The ERP Data and Information Level Integration Maturity Matrix for MNG Group is presented in Table 3.

5.2 *Case Studies: System Vendors*

5.2.1 *Tepum Technology*

Tepum Technology is the ERP solution partner of Microsoft for Turkey. The firm is one of the vendors of Microsoft Dynamics AX and NAV (ERP) systems and works in the area of implementing ERP systems in large-scaled investor and entrepreneur companies of the Turkish construction industry. As mentioned by the participants from the Tepum Technology, the construction enterprises mostly implement and use Dynamics AX as their ERP system.

The participants from the Tepum Technology mentioned that most frequently used modules of Microsoft Dynamics AX as General Accounting (from Financial Management module group), Inventory Management (from Logistics group) and Production. Other modules inside Dynamics AX that are used by the construction enterprises include HR, Project Management, and Customer Relationship Management (CRM). The most efficiently used modules for the construction industry are mentioned as Budget, Bidding, Sales, Purchase and Accounting.

During an implementation of Dynamics AX system all the meta-level activities mentioned in the framework needs to be completed. The enterprise-wide metadata model is named as ‘Masterdata’, and it should be built before implementation.

File exchange method is used between the Administration and HR modules in Microsoft Dynamics AX ERP system implemented within a construction industry organisation. On the other hand, Accounting, Production and Logistics modules make use of file to database and database to file exchange methods especially to acquire information from/and to export information into spreadsheet applications. The systems’ modules can make use of different databases, which are integrated with Data Replication method.

All modules in Dynamics AX can make use of the shared data in physical files and residing in a database, with the help of the APIs. The modules of the Microsoft Dynamics AX system can accomplish file and file to database transformations.

In Microsoft Dynamics AX system, Topic Maps are not used for organising the enterprise-wide information but for presenting the ERP related topics to users when providing system support. In addition, Online Analytic Processing (OLAP) applications in Dynamics AX ERP systems make use of data mining techniques. The system also makes use of search engine algorithms and local/intra-organisational search engines. The ERP Data and Information Level Integration Maturity Matrix for Microsoft Dynamics AX systems is presented in Table 4.

Table 4. EMM for Microsoft Dynamics AX.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
+		+		+		+	
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.	+	Shared File	+	F→F	+	Sem. Web.	
F→DB	+	Shared DB	+	F→DB	+	Knowledge Disc. DB	+
DB→F	+	Federated DB		DB→F		Other	+
DB→DB	+			DB→DB			

5.2.2 *Oracle corp – Turkey branch*

Oracle Corp. was founded in 1977 and is now a provider of various enterprise ICT solutions. Oracle has 275,000 enterprise customers from 145 countries. The company is considered as the leader in the database industry.

The company has a wide product range serving for business intelligence, business application, enterprise planning and management. The company offers different enterprise software systems such as Oracle E-Business Suite, JD Edwards, Peoplesoft, Siebel and Hyperion to satisfy the needs of different businesses. As well as these ERP systems, the company offers solutions for Customer Relationship Management, Supply Chain Management and Advanced Budgeting.

The set of ERP Systems offered by Oracle include Financials Management, Analytic Analysis, Capital Assets Management, Finance Management, Properties Lifecycle Management, HR Management, Training Management, Human Capitals Management, Enterprise Performance Management, Campus Management, Supply Chain Management, Order Management, Sales Management, Planning, Production Management, Customer Relationship Management, Marketing Management, Service Management, Purchasing, Project Management, Equipments and Technology Management, Maintenance and Advanced Maintenance Management modules.

Prior to an Oracle enterprise level system implementation, all meta-level activities are completed. The existing data is identified through the Data Dictionaries and an enterprise wide Meta Level Data Model is developed. Topic Maps are also used in Oracle ERP systems for information classification.

In terms of the integration methods, the file exchange method is never used in Oracle’s ERP systems as all the product lines of the company are database oriented. In fact, if a need to connect external systems or applications to the ERP in use appears, then file to database and database to file exchanges are accomplished through API’s and web services. As most Oracle ERP modules work with a single shared database, the Data Replication is not used as an exchange method. In fact, Data Replication is always used for back-up reasons.

Table 5. Generalised EMM for Oracle ERP systems.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
+		+		+		+	
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.		Shared File		F→F		Sem. Web.	+
F→DB	+	Shared DB	+	F→DB	+	Knowledge Disc. DB	+
DB→F	+	Federated DB		DB→F	+	Other	+
DB→DB				DB→DB	+		

Table 6. EMM→ Minimum Set of Requirements for Integration Maturity.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
+		+					
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.		Shared File		F→F		Sem. Web.	
F→DB	+	Shared DB	+	F→DB	+	Knowledge Disc. DB	+
DB→F	+	Federated DB		DB→F		Other	
DB→DB				DB→DB			

The file sharing method is generally not used inside the Oracle ERP systems, as all modules can access the data through the shared centralised/or decentralised single database. Another share method – Data Federation method (i.e. the use of multiple different databases within a single interface) – does not usually need to be used as Oracle databases are generally formed within a grid structure, and can be reached as a single data repository.

In order to exchange information between different data models, the Oracle ERP systems make use of file to database and database to file transformations. If a need appears for transfer of data from an existing database (used within the enterprise) to an Oracle database, then data transformation between databases is accomplished by the help of transformation applications.

In Oracle ERP systems, an application named 'Secure Enterprise Search' makes use of the ontologies and Semantic Web concepts. The OLAP reporting applications make use of Data Mining and Knowledge Discovery techniques. In addition, Oracle's different solutions on reporting and Business Intelligence make use of other Relate-Search-Retrieve methods. The generalised ERP Data and Information Level Integration Maturity Matrix for Oracle ERP systems, is presented in Table 5.

5.3 *Analysis on data and information level integration maturity*

The results obtained from the case studies indicate that data identification and data cataloguing are the basic set of Meta Level Activities to be conducted prior to an ERP implementation.

On the other hand, in terms of Integration Methods, the exchange methods such as file to database and database to file are supported within all ERP implementations. In parallel, access to data from a shared data repository is the inevitable need for an ERP system. The data transformation methods vary from system to system, but the most commonly referred method is file to database data transformation. The results also demonstrated that ERP systems usually support knowledge discovery techniques such as data mining. In light of these findings, the EMM showing the minimum set of requirements in terms of meta level activities and integration methods is presented in Table 6.

ERP systems that either conform to these minimum requirements (given in Table 6) or offer at least one method for exchange, sharing, transformation, reasoning and a method for meta-level activities can

Table 7. EMM→ Construction Industry Case Studies.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
++		++		+		-	
Data Movement Frequency							
Batch Processing				Real Time Processing			
30%				70%			
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.	++	Shared File	+	F→F	+	Sem. Web.	-
F→DB	++	Shared DB	++	F→DB	+	Knowledge Disc. DB	++
DB→F	++	Federated DB	-	DB→F	+	Other	+
DB→DB	-			DB→DB			

Table 8. EMM→ Case Studies with System Vendors.

Meta Level Activities							
Data Identification		Data Catalogues		Ontology/Taxonomy Topic Maps		Meta Level Data Model	
++		++		++		++	
Integration Method							
Data Exchange Methods		Data Sharing Methods		Data Transformation Methods		Relate/Search Retrieve Methods	
F. Exch.	+	Shared File	+	F→F	+	Sem. Web.	+
F→DB	++	Shared DB	++	F→DB	++	Knowledge Disc. DB	++
DB→F	++	Federated DB	-	DB→F	+	Other	++
DB→DB	+			DB→DB	+		

be regarded as the system with minimum data and information level integration maturity.

6 SUMMARY AND CONCLUSION

The study was initiated with the aim of determining the integrative function of the ERP systems used in the construction industry. The first two phases of the research included a literature reviews on i) the function of ERP systems and on their role in construction industry enterprises and ii) the methods for enabling systems integration at the data, application and web service levels. Following this, a data and information level integration framework was developed for formalising the activities for achieving data and information level integration throughout the implementation of the ERP systems. In parallel with the research objectives, the ERP Data and Information Level Integration Maturity Matrix (EMM) was developed as a metric to evaluate the maturity in data and information level integration achieved by the ERP implementation. In the final stage of the research the applicability of this metric is validated through four case studies. The case studies also helped in evaluating the integration maturity level of the systems implemented. The following EMM (illustrated in Table 7) summarises the findings of the case studies conducted within the construction industry.

The findings indicate that both ERP system implementations for the construction industry organisations conforms to the requirements of minimum data and information level integration maturity. In fact, the use of methods such as database replication, the use of the federated databases in database model transformation, and the use of semantic models and search have never been observed.

The findings of the case studies conducted with the system vendors (shown in Table 8) indicate that both ERP systems offered by them for the enterprises working in the construction industry conforms to the requirements of minimum data and information level integration maturity.

The comparison of the offered and the implemented integration methods might indicate that the organisations do not fully benefit from the different integration mechanisms offered by the ERP systems, but it is impossible to reach a scientific conclusion towards this direction as the sampling is not sufficient (for reaching such a conclusion).

The results of the study indicate that the implementation of an ERP system contributes to data and information level integration within the LSEs in the construction industry. Another finding of the research indicates that an ERP implementation effort facilitates the formation of a meta-level data layer within the enterprise. The case studies revealed that ERP systems play a key role in information centralisation. In addition, the study has also found that centralised information facilitates the decision making process and enables the management of various different tasks in a more efficient manner.

The case study participants pointed out that the developed framework can aid in formalising the stages of an ERP system implementation, and the developed metric (EMM) can be helpful in assessment of the data and information level integration maturity.

Further research will focus on validating the applicability of the EMM metric and evaluating the integrative function of ERP systems through more case studies and also in service and application level integration.

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Semantic representation of product requirements for true product knowledge management

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ABSTRACT: To achieve true product requirements knowledge management and improving the level of automation in other related knowledge-intensive tasks, we need a common understanding of product requirements that is shared by humans and computers. This suggests the use of a knowledge representation paradigm that allows the semantic representation of product requirements information. This paper presents an outline of a knowledge representation system (KRS) for this wide sort of technical knowledge. This KRS is based upon the same representational means used for the semantic representation of natural language expressions, although the knowledge representation framework (KRF) provided to support meaning representation is one adapted to the domain of product requirements. The KRF takes into account the general structure of product requirements and provides a collection of representational means suitable for capturing the meaning of these information units. We also report on how the KRS is being implemented and on its intended use for creating, disseminating and processing product requirements knowledge bases.

1 INTRODUCTION

The development of new products involves an iterative process intended first to establish requirements based on customer needs, and then to transform them into functional and performance product specifications. A fundamental source of product requirements and specifications (simplified as product requirements or PR from now on) are the codes and standards used in every area of technical activity.

Although architects and design engineers have numerous computer-aided tools for modeling, simulation, and analysis that efficiently support product design, computer-based engineering knowledge management has clearly lagged behind, and this is the case of product requirements knowledge management.

This technical knowledge management will facilitate a shared understanding of the product requirements, a critical issue in collaborative product development [Roy et al., 2005], and also it will enable to reuse design knowledge and experience, thus reducing the time and cost of the development cycle for similar products [Chen et al, 2007]. On the other hand, an efficient normative knowledge representation and management can improve the level of automation of different knowledge-intensive tasks to which standards can be applied [Bravo-Aranda 2006]: from normative information retrieval to knowledge query, from (partial) conformance checking of design solutions to project certification.

As a previous step to achieve true product requirements management, it is essential to develop a knowledge representation system (KRS) for this wide sort of technical knowledge, preferably, in a manner that it can be readily shared on the Internet. Such a KRS, as a knowledge representation language, must have well defined features. The most important feature, to which other features subordinate, is that the KRS must allow the semantic representation of product requirements information. In this regard, the meaning of product requirement expressions (i.e., of a limited and relatively ordered subset of natural language) can be described independently of a specific language, provided that we represent its fundamental meaning or core meaning. Therefore, we need a comprehensive repertoire of representational means that permits an adequate description of the semantic contents of product requirement information units, both as independent and as connected units, be it on paper or in a computer.

The paper outlines the KRS we are working on, and presents its intended use to support different knowledge-intensive applications. This KRS is based upon the same representational means described in [Helbig 2006] for the semantic representation of natural language expressions. However, the knowledge representation framework, or repertoire of representational means, presented in the paper is one adapted to the domain of product requirements. In the following, we analyze first the general structure of product requirements by distinguishing the

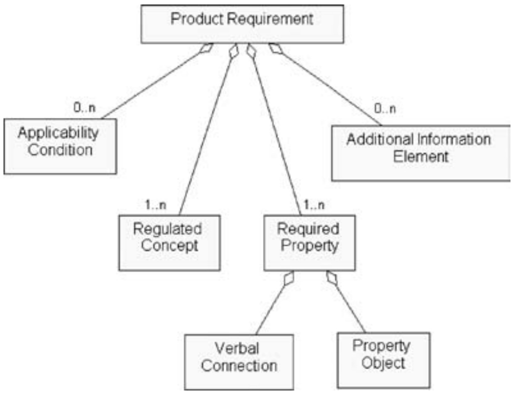

Figure 1. General structure of product requirements.

main component elements of these information units. Then we describe the basic representational means–concepts and semantic relations- and the framework developed –ontology of conceptual entities and repertoire of semantic relations- for semantic representation of product requirements. Finally, we report on the intended use of the KRS to support different knowledge-intensive services and applications.

2 SEMANTIC GENERAL STRUCTURE OF PRODUCT REQUIREMENTS

A product requirement is a stipulation that should be met by a product's entity. Product requirements are information units that establish the properties required of a product (in this sentence, properties should be understood in the broadest sense). Analysis of PR natural language expressions from different fields show their complexity and diversity, where this diversity refers to the varied semantic patterns in which product requirements occur.

As a stepping-stone to managing PR complexity and diversity, it is most useful to identify the parts that typically may compose their general structure. This general structure is described by distinguishing the coarse-grain semantic components of a PR. As shown in Figure 1, we differentiate four components: (1) applicability conditions, (2) regulated concept, (3) required property, and (4) additional information elements. The structure shown in Fig. 1 extends and semantically enriches the one presented in [Harris 1980] for the purpose of classifying requirements in technical standards and codes. We give a description of these components in the paragraphs that follow.

Applicability conditions. Set of conditions that limit the range of validity of a PR. This semantic component collects the circumstances in which a PR is applicable, and so it can be identified by answering the question: In which circumstances the regulated concept should have the property required? Applicability conditions describe an essential part of the context in which a PR is valid; i.e. a part that cannot be omitted without loosing or changing a PR's original meaning.

In the sentence(s) of a PR, there might be zero or more applicability conditions. When there is no applicability conditions, the regulated concept should meet what is established by de PR in whatever circumstances may concur. Usual linguistic realizations of this type of component are prepositional phrases or phrases preceded by conjunctions such as: if…, when…, in (the) case of…, etc.

In the knowledge representation system, the semantic associated with a set of applicability conditions is collected as that of a logical combination of elemental applicability conditions –for instance, a conjunction or a disjunction-, and by capturing the semantics of every single applicability condition (this is similar to the way it is done for the nucleus of a PR, explained below). For the time being, it suffices to say that the most important representational means for describing the meaning of such phrases is that provided by the repertoire of semantic relations identified).

As a result of semantic analysis of applicability conditions, it is possible to build a classification for these components. Some of the classes identified are: (sub)class condition, structural condition, attribute-value condition, location condition, use condition, event condition, state condition, etc. Such classification is not explicated in more detail in the paper that is intended to present an outline of the KRS.

Regulated concept. Regulated concept is the entity for which a PR stipulates certain property (the required property). The concept regulated by a PR can be ((the value of) an attribute of): a product entity –i.e. of one of the elements with real existence that constitute a part of a product's structure, including the product itself-, a set of product entities, or one or more specific entities from (one) such a set. However, some requirements may regulate concepts that only indirectly refer to product entities (That is the case for requirements which regulate an activity, or an activity-related entity, that should be performed with/on a product. Last kind of requirements are not further pursued in this paper).

In a PR with several potential regulated concepts, the straightforward way of determining it is by identifying the required property and answering to the question: To which concept(s) belong that property?

In the sentence(s) of a PR, the regulated concept may be expressed by a single noun – for instance, "pipes …" – or by a noun phrase that can have a more or less complex structure – for instance, "the thickness of pipes' interior wall coating…"

In the case of a regulated concept that refers to specific elements in a set of product entities, its expression usually includes, in addition to the noun phrase designating the elements, one or more conditions that determine those elements in the set that are regulated. Such conditions are analogous to applicability conditions. Every PR can be paraphrased to a standard form of expression in which the regulated concept corresponds to the subject.

In formal terms, the concept regulated by a PR is a component of a product's domain ontology (i.e., of the ontology that defines that product's model). In addition, the concept regulated by a PR can be mapped to one conceptual structure in the KRF's ontology of product entities (a conceptual structure is a set of concepts interconnected by cognitive relations) (see below the paragraphs dealing with the roles of ontologies in the KRS).

The user of a system for querying the KB of PR will be able of posing questions about which PR should a given product entity fulfil using both domain and general terms (such as the ones included in the meta-model represented by the product entity ontology). Example: Which PR's should pipes meet ?

A PR's regulated concept and property required constitute, as a whole, what is called the nucleus of the PR. The nucleus of a PR is the main semantic component because it conveys the essential or core meaning of the PR as an information unit.

Required property. Required property is the term used for that part of a PR's nucleus that expresses what is required of the regulated concept. The identification of the required property by a human interpreter is seldom a problem.

In the standard form of expression of PR, the required property corresponds to the predicate of the sentence that is its nucleus. From the point of view of linguistic realization, the required property is a complex component including both the verb or verbal phrase, which is the element that connects it with the subject (i.e. with the regulated concept) –the subcomponent *verbal connection* in Figure 1-, and the remainder of the nucleus that completes what is said about the subject –named *property object* in the same figure.

The last subcomponent can have very varied linguistic realizations as varied are the classes of properties a PR may require. The diversity of types of PR is due to the varied semantic nature of the properties found in product requirements. Instances of the property required are: the existence of a certain structural component, a constraint on the value of an attribute, a functional (qualitative) property, etc.

In the KRS, the core meaning of the nucleus of a PR, and therefore of the PR itself, is captured basically by the appropriate semantic relation. This semantic relation connects, at least, two concepts: the regulated concept to the concept in the property object. These concepts are designated by the names of (cognitive) roles that correspond, respectively, to the domain and range of the relation.

In a knowledge query system, the semantic captured for different types of required properties allow the user to selectively query the properties of a given product entity, or determine which concepts should possess a specific property.

Additional information elements. These text components of PRs provide some type of explanation or other complementary information about the PR or one of the concepts involved in it. They are easily identified because they do not express what is stipulated or for which concepts it is stipulated, as it is the case of the components previously described, and therefore they do not constitute an essential part of PR.

In spite of their informative nature, we collect their general semantic and in some cases, in which such information is important and/or useful, their semantic in more detail. Two frequent cases are the rationale of PR and definitions of concepts.

A typical additional information element is that expressing the rationale of what a PR stipulates. This kind of justification may be either directly established as a statement that explicate the purpose of what is stipulated or by reference to other "more general" requirement the current PR contributes to fulfil.

The capture of this kind of semantic relations allows navigating through the KB of PRs and thus answering questions such as: What's the reason to meet a given PR? Or, in a top-down direction, How can a specific PR be fulfilled?

Another frequent additional information element is that giving a definition of a concept involved in a PR. If it is well-formulated, a concept definition gathers the necessary, and may be also the sufficient, properties for the concept to hold. This type of knowledge can be used to infer from the known properties of something if it can be classified as a given concept, and also to infer the properties that a thing must have if it has to match the pattern provided by a concept's definition.

3 KNOWLEDGE REPRESENTATION FRAMEWORK

Product requirements are basically expressed in natural language and so we focus on the representation of meaning of this kind of information. Several disciplines in the field of Artificial Intelligence, mainly Knowledge Representation and Natural Language Processing (NLP for short), are concerned with this problem. In those disciplines, there exists a long tradition in the use of semantic networks as a means for capturing the meaning of natural language expressions. Concepts, represented as nodes in semantic networks, and their mutual interrelations, or semantic relations, that are represented as labeled-links, are the basic structural elements in this knowledge

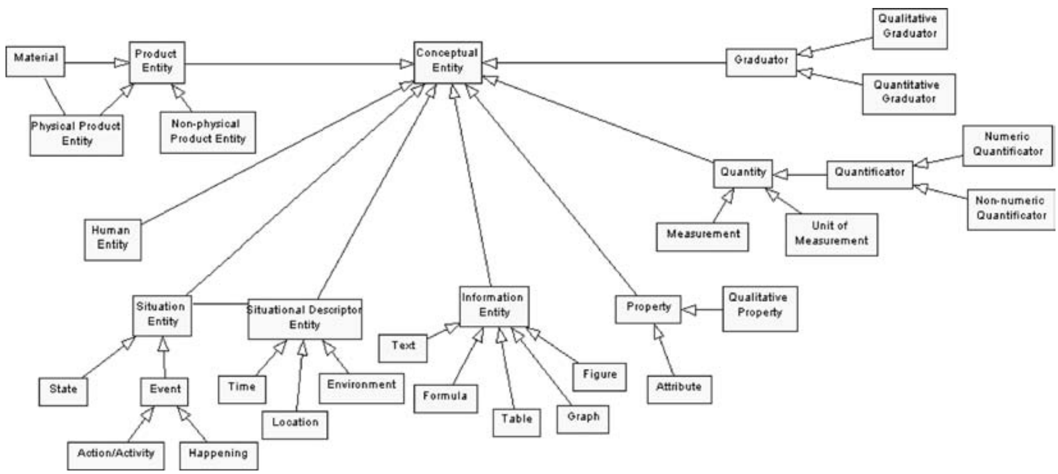

Figure 2. General ontology of conceptual entities.

representation paradigm. We adopt the same basic elements for representing the semantics of product requirements. However, the ability to represent PR semantics essentially depends on the collection of concrete representational means provided by the KRS; i.e. of a KRF appropriate for the PR domain. We briefly describe the main elements of such KRF; namely, their ontology and repertoire of semantic relations.

3.1 *General ontology*

The general ontology is a hierarchy of conceptual entities that collects the semantic classes or sorts of concepts about which something can be stated in PR expressions. We need this classification in order to formally define the semantic relations included in the framework. As it is explained later, semantic classes in this ontology must be appropriate for characterizing the domains and value ranges of semantic relations. In this sense, the classification of conceptual entities allows one to decide if a given relation may be semantically representative of the meaning, or whether this can be excluded, of (a part of) a PR by examining the classes of the concepts related.

The classification of conceptual entities is presented in Figure 2, and it should be considered as only the upper part of the whole conceptual hierarchy needed, especially with regard to those subjects that are specifically relevant in the PR domain (see 3.2 bellow). In addition, the ontology must be considered an initial version that can require modifications as more experience is gained in PR modeling.

The most general class in the hierarchy is *conceptual entity*, which represents and comprises all things about which a PR can state something. At the highest level of the hierarchy, there are eight main subclasses of conceptual entities:

Product entity: For physical and non-physical products and the elements that compose their structure (Examples: a building or a computer program);

Human entity: For humans and human organizations whose needs are in the origin of product requirements and that perform activities as agents (Example: the user of a product);

Situation entity: For situations or states of affairs, such as states (static situations) and events (dynamic situations) (Examples: activities or limit states as a kind of event);

Situational descriptor entity: For the concepts used in describing situations with regard to their spatio-temporal embedding (local or temporal specifications) or environmental embedding (Examples: locations for components and actions and other boundary conditions);

Information entity: For those information objects, such as formulas, tables, graphs, etc., which are usual means of expression in PR documentation and are often referenced by PR;

Property: For attributes (i.e. properties that have associated a value) and other types of properties (Example: an activity-related functional property, as, f.i., easy to clean);

Quantity: For expressing the quantitative aspects of concepts (i.e., numbers and measurements); and

Graduator: For a more specific and graded specification of properties or for qualification of quantities (Example: more …than).

3.2 *Ontology for physical products*

This (sub)ontology develops the branch of Physical Product Entity in the general ontology. It collects

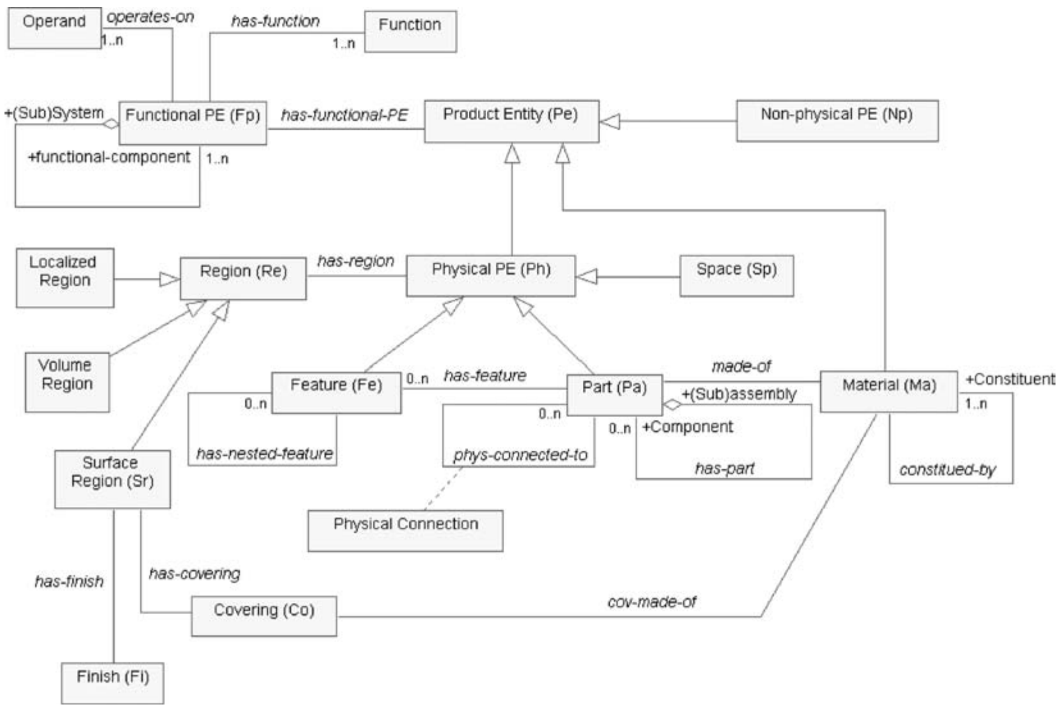

Figure 3. Subontoloy of physical product entities.

general concepts, independent of a particular product domain, that are used in describing material products. In this sense, the role of this ontology in the KRS is twofold. On the one hand, product ontologies of specific product domains are developed following the conceptual framework given by this (sub)ontology. This means that the concepts relative to specific physical products, expressed by groups of words in PR, can be mapped to conceptual structures in this ontology (i.e., to those that represent their semantic). On the other hand, the (sub)ontology also collects a subset of semantic relations that capture the basic semantic of those PR establishing the structure or material that form a physical product (see section 3.3 bellow). The (sub)ontology is shown in Figure 3.

The highest class in the subhierarchy is the abstract class Physical Product Entity, which represents any of the elements with real existence and cognitively distinguishable that are part of a material product's structure, included the product itself. There are four subclasses of Physical Product Entity: Part, Feature, Covering and Space. We associate with these classes the semantics of the concepts so designated:

Part: For the physical components of a product (that in turn can be constituted by other parts; *Feature*: For the elements of relief in a part, such as prominences or holes; *Covering*: For the material layers that cover the surface of a product entity region with different purposes; *Space*: For spaces that serve to contain materials or other product entities and/or where activities are performed.

The (sub)ontology also includes the concepts *Region* (for the parts of a Physical Product Entity that are not classifiable under the previous concepts), *Finish* (for surface finishes) and *Material* (for the material of which parts or coverings are made of, or other substances); and several cognitive roles such as, for instance, constituent –that designates a material of which another material is made of.

Figure 3 also shows the subclass of Product Entity named *Functional Product Entity*. This concept is useful for both physical and non-physical products. A FPE is a product's component that is not named in the text of a PR but it is referenced as an element of unknown class that should fulfil a specified function.

Finally, the (sub)ontology also collects a set of structural semantic relations the meaning of which can be well understood from their names and the semantic classes they connect. We will discuss the meaning of these and other semantic relations in next section.

3.3 *Semantic relations*

Semantic relations are the most important representational means for describing the meaning of the individual phrases and sentences that constitute the

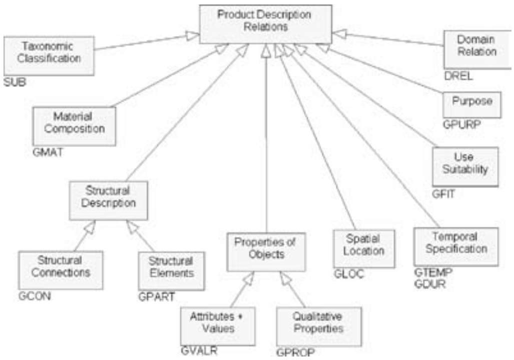

Figure 4. Semantic relations for the description of physical products.

text of a PR, such as the PR nucleus or each applicability condition, and also of the connections between phrases or PRs. In accordance with the distinction between 'surface structure' (the particular form used to express a piece of information in natural language) and 'deep structure' (the meaning representation of the corresponding natural language text expressed in a given formalism), semantic relations correspond to deep case relations [Fillmore 1968] that could be possibly expressed by different linguistic realizations in the same language and in different languages. In this way, for a relation to be included in the framework, it must capture the essential meaning of a class of meaningful links between concepts. In addition, these semantic relations must have a unique interpretation and, obviously, be relevant to the domain of product requirements. Keeping in mind these general guidelines, we are elaborating a repertoire of semantic relations that either are adopted from those presented in NLP literature or were identified as part of our research. Figure 4 shows a classification, organized by thematic subareas, of the semantic relations identified for product description.

In Figure 4, only the highest level or general relations are included (see the case of the GPART relation bellow as an illustration of this).

Semantic relations are associated with natural language expressions in several ways. First, the meaning ascribed to a semantic relation can be described by natural language expressions. Second, there are one or more question patterns associated with each semantic relation that refer to the kind of information it serves to represent. Third, it is possible to associate a NL standard form of expression with each semantic relation. This standard form can be used to express with words the information represented by multiple conceptual structures including the relation. This is necessary when, for instance, a knowledge query system infers an answer to a question that then must be presented to the user.

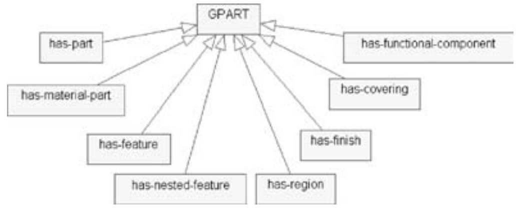

Figure 5. The generalized whole-part relation (GPART).

The formal definition of a semantic relation is specified as a Cartesian product of the semantic classes their arguments must belong to; i.e. of the classes of concepts that characterize the domain and the value range of the relation. Moreover, some relations include a collection of axiomatic rules that express their logic properties, constrain their meaning, and in general allow to make logic inferences.

As an illustrative example, let us consider the semantic relation GPART. GPART is the label used for the generalized whole-part relation; i.e., a generalization of the different semantic relations that describe, in a general sense, what is the physical structure of a product. Specifically, GPART is defined as a generalization of the relations: has-part, has-material-part, has-feature, has-nested-feature, has-region, has-functional-component, has-covering and has-finish, all included in the (sub)ontology of physical product entities. This is represented in Figure 5.

GPART is formally defined as:

$$\text{GPART: } [Pa \times Pa] \cup [Pa \times Fe] \cup [Fe \times Fe] \cup [Ph \times Re] \cup [Sr \times Fi] \cup [Sr \times Co] \cup [Ph \times Fp]$$

The expression (O_1 GPART O_2) stands for [O_1 has (the generalized) part O_2]. We can associate with GPART the questions patterns: What are the (component) parts of O_1? Which (component) parts does O_1 have?

The relation GPART, like the relation has-part, is transitive, asymmetric and not reflexive. As a well-known example of axiomatic rule, the transitivity of GPART can be expressed by:

$$(O_1 \text{GPART } O_2) \wedge (O_2 \text{GPART } O_3) \rightarrow (O_1 \text{GPART } O_3)$$

4 USE OF THE KRS

In the light of the structure identified for product requirements, the classification of conceptual entities that may occur in these information units, and the types of semantic relations that capture their core meaning, and also given that product requirements are normally expressed in textual form, a semantic annotation approach appears to be the most suitable way of implementing the KRS.

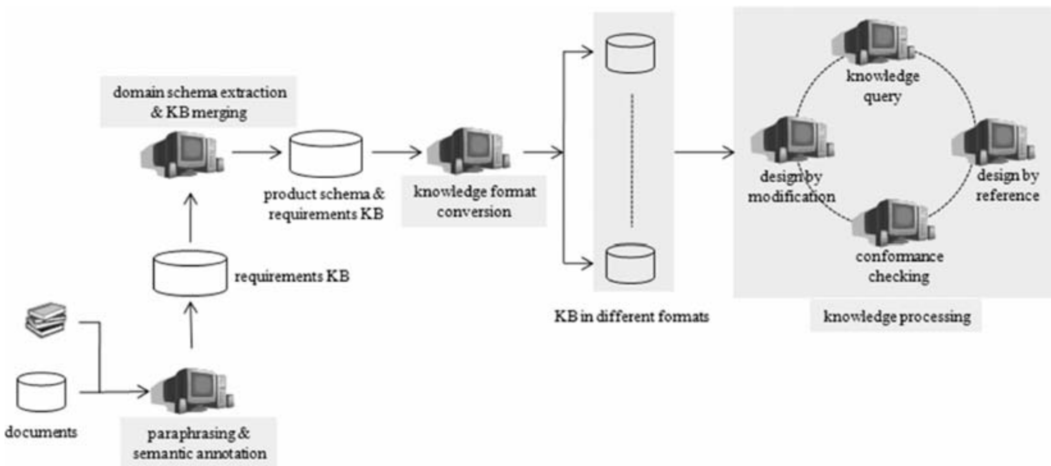

Figure 6. Use of the KRS.

For practical reasons, most important of which is the fact that although information units follow clear structural patterns they also exhibit some variability with regard to the specific information contents in the structural elements, an XML-based semantic mark-up language was selected as the means of implementation. As a standard meta-language, XML can be used to store, transport over the Internet, and, thanks to the XML-based technologies already available, manage the information about product requirements. With this goal in mind, we are developing a product requirements mark-up language specified in XML Schema.

The hierarchical structure identified for PR information units fits very well to the typical organization of contents in XML documents. In addition, the labels enclosing elements in XML documents are used as semantic annotations that express the semantic classes and roles of concepts and the core meaning of PR structural components (such as the PR-nucleus o the applicability conditions).

On the other hand, we use the attributes of XML elements for several purposes. First, and as it is customary in the semantic web, attributes are used as a means of assigning a unique identifier to every concept. These identifiers serve to refer to the concepts independently of lexical name variations that are frequent in PR documents (or even in the case of linguistic indirect references as, for instance, those made by pronouns). Second, we also use attributes to collect several semantic features of concepts and conceptual structures that go beyond its core meaning (that in the case of conceptual structures is expressed by the kind of semantic relation representing its meaning). We capture in this way, for instance, the affirmative or negative character of a PR, or its character as regulating element; i.e. its mandatory or permissive character. The combinations of values for these attributes allow a more accurate representation of a PR's semantics. For instance, if a PR is mandatory and is a negation, it must be interpreted as a prohibition.

With regard to a PR document, the XML schema has two general aims: (1) enabling to build an object-oriented model of domain products that fulfils the information requirements expressed by the document, and (2) converting the document, by semantic annotation, into a KB that provides the necessary knowledge resources to different applications and services that exploit them in performing knowledge-intensive tasks.

A first version of the XML schema that specifies the grammar of the product requirement mark-up language is being used to semantically annotate one of the documents contained in the Spanish building code (Código Técnico de la Edificación). We are obtaining good results in the sense that the schema is able to capture the semantics of a very high proportion of information contents, and available XML tools can be used to query the resultant XML document.

Figure 6 illustrates the intended use of the KRS to support different knowledge-intensive tasks that process PR information.

Starting from textual documents or standards that collect the requirements for a product, it may be necessary some paraphrasing of certain requirements to transform them into the corresponding standard form (i.e., one that fits the structural pattern of a requirement type).

Then, we can use an ontology-based annotation tool or XML editor to create a product requirement knowledge base (requirement paraphrasing & semantic annotation phase in figure 6).

A later analysis of the resulting KB can be carried out for extracting a product model, and this domain model may be enriched semi-automatically making use of an ontology development tool. This product model is also converted into an XML document and merged with the product requirements knowledge base, becoming the product schema and requirements knowledge base (domain schema extraction & KB merging phase in figure 6).

This KB belongs to a kind of product and/or product development project, and can be stored in a knowledge repository for later utilization. Software translators are used to transform such XML documents into different application formats suitable for processing (knowledge format conversion phase in figure 6).

Finally, the knowledge can be processed by the corresponding software application or services, to carry out a knowledge-intensive task (knowledge processing phase in figure 6). Some of such tasks are knowledge query, conformance checking, design by modification or by reference (based on matching product requirements over a project knowledge repository), etc.

5 SUMMARY AND CONCLUSIONS

To achieve true product requirements knowledge management and to improve the level of automation in other PR-related knowledge-intensive tasks, we need a common understanding of product requirements that is shared by humans and computers. This suggests the use of a knowledge representation paradigm that allows the semantic representation of product requirements information.

In this study, we presented an outline of a knowledge representation system for this wide sort of technical knowledge. This KRS is based upon the same representational means used for the semantic representation of natural language expressions, although the knowledge representation framework provided to support meaning representation is one adapted to the domain of product requirements.

Main characteristics of the Knowledge representation framework are:

– It takes into account the general structure of product requirements defined by the coarse-grain semantic components of these information units.
– It provides the following sets of representational means: (1) a general ontology of conceptual entities for the classes of concepts that occur in product requirements; (2) a (sub)ontology for describing physical product entities that also collects the main semantic relations between concepts in the (sub)ontology; (3) a repertoire of semantic relations used to capture the core meaning of product requirements' phrases and sentences; and (4) other complementary representational elements, such as sets of axiomatic rules and semantic features, that are used for logic inference and also to describe more accurately the semantics of product requirements.

The paper concludes by discussing the way in which we are implementing the KRS and its intended use. For this purpose an XML-based semantic mark-up language is being developed and used to convert PR documents into knowledge bases.

The results are good in the sense that the schema is able to capture the semantics of a very high proportion of information contents, and available XML tools can be used to query the resultant XML document.

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HyperUrban: Information and communication driven design era

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ABSTRACT: This paper presents the concept of HyperUrban (Zreik, 2008) which suggests an integrated media city design approach. It observes the evolving of Information and Communication Practicing (ICP) as well as their impact on both Urban Information System Design and City Design. Regarding the important development and use of "Information and Communication Technology" (ICT), the HyperUrban approach considers the complex shifting of the interrelation between the "City" and the "ICP". In this context the Integrated Urban Information System Design could not be dissociated anymore from the "traditional" "City" Design itself. HyperUrban suggests reflecting on a "Design Bridge Approach" for a sustainable Integrated Media City Design.

1 INTRODUCTION

1.1 *HyperUrban's context*

It is obvious that ICT have brought important impacts on its environment and feedback on itself.

The development of cell phones and wireless technologies has amplified the integration and the use of ICT in so various domains. In this paper we interested in the design of an integrated urban information system. Our problematic is closed to both concepts: the "Cognitive City" (Tusnovics, 2007) and the "Media City"[1].

Therefore the HyperUrban has fundamental difference in the way it perceives and manages the design process. It considers on the first hand ICP as the kernel of any Information Management System (IMS) and on the other hand the future city as integrated media system.

HyperUrban's approach considers the shifting of the concept "City" as a complex urban space producing, conserving, exchanging, transferring, transacting, etc: information related to services and products. Today every city contains and bellows to many different other "Cities" such like: tele-city, virtual city, augmented-city.

Digital Social Networking (DSN) (Mazzoni, 2006) as well as Second Life concepts has proved that inhabitant can use a physical city to live in it, to create another one or co-construct an ephemeral one.

Ubiquitous technology has had important impacts on temporal reasoning as well as on public and private spaces perceiving.

In sum information, communication, time and space have all been involved in a continuous shifting process leaded, for the while, by ICT practicing. Every Information Management System Design should take into account of this fact.

HyperUrban, points out an important conceptual break (fracture) in Urban Information Management System Design. City Design Actors use IT in their design process but very often they don't consider ICT as appropriate part of the Urban Space. It is either for ICT actors who don't consider at all the Urban Space (as set of parameters or constraints) in their designs, however they still using, inspiring, living, and developing in an Urban area.

HyperUrban's approach aims to bridge together those tow sides of design in order to define the architecture of Integrated Urban IMS. The main focus of our research project is to set up an adapted system requirements analysis methodology.

2 "CITY"S HYPER SPACES

As we noticed above a "City", in HyperUrban approach, is seen as an "open-closed" space of Information and Communication. Until very recently, every "City" has had its own "Integrated Urban Information Management System": the city itself.

Today[2], most of the major "cities" have chosen the "information society" concept and adopted special policies to:

– Support important ICT research and development projects.
– Ensure, to the inhabitants, easy and low-priced access to the digital business spaces.

[1] http://www.dubaimediacity.com/

[2] May 2008

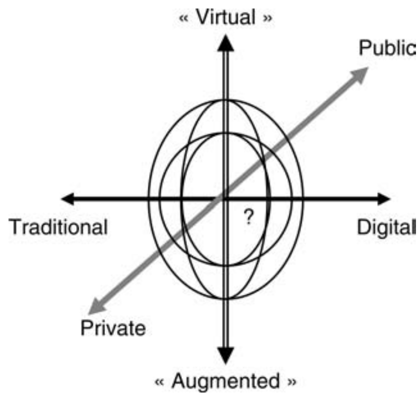

Figure 1. Inhabitant's Information and Communication Space.

More than expected, inhabitants have rapidly integrated and experienced Tele-information and telecommunication different offers and services. This has lead to new usages and to a non stop ICT sub-products (mainly wireless networking technologies).

Hence, access to information and communication facilities has become, for public and privates spaces, as crucial requirement, such like energy, protection or security. This fact has, very quickly, been considered, in a certain (and limited) way, by Urban Planning, Building and Construction firms. Very briefly, most of them have added ICT requirements to their design check lists.

HyperUrban believes that Inhabitant Requirements are not only limited to this aspect (adding ICT to his or her traditional spaces), Practicing ICT has changed the way he or she is perceiving and living the called "City" spaces. Most of inhabitant spaces have already passed through the city spaces to explore and live various kind of extra or outer spaces.

At home, office or in a garden every inhabitant can enjoy a multidimensional Information and Communication areas:

- traditional "touchable" dimension
- digital dimension through his or her ICT devices,
- virtual "reality" dimension
- augmented reality dimension
- public dimension, when he or she is involved in a public communication (tele-conference, social networks) in a private place
- private dimension, when he or she is involved in a personal communication (or a social network session) in a public place
- …

It is important to notice that most of those information and communication areas are completely independent of the physical place where they occur.

This first fact shows that the spaces functions have already shifted. From a spatial point of view, neither public neither private area is no more limited to discrete closed geometrical envelops (inhabitant can work, buy, sell, etc in a very intimate or public place). It is either if we consider the temporal aspect of the city. The perception of time perceiving and its management have encountered important shifting. Asynchrony communication supported by powerful networking has allowed inhabitants to manage their time the way they would like independently of any spatial or temporal constraints.

As a first statement, HyperUrban confirms that:

- Spatial and temporal relations between inhabitant and his or her city have deeply shifted.
- We are witnessing the emerging of the "Augmented City"

This will obviously have impacts on "City" design and consequently on Workplace and Home design.

To better understand the idea of HyperUrban we will try to present it through its technological aspect.

3 HYPERURBAN: "AUGMENTED CITY"

The concept "Augmented City" emerges if some 'Augmented Reality'[3] technologies have been used into "City" studies, perceptions, representations and design.

By the following we will try to state the main technological concepts that have lead to the domain of "Augmented City":

- 'Augmented Reality' (AR) deals with the combination of the called "real" world and "digital data management". At present most AR applications uses live video imagery which is processed and augmented by the addition of computer generated graphics. AR has been introduced by (Wellner, 1993) as the opposite of virtual reality.[4] The goal of AR is to augment the real world with information handling capabilities. AR is a kind of mediated reality that is able to augment the perception of a given 'reality'
- 3D modeling, imagery and video technologies are very suitable for creating an accurate record of city life cycle (historical and perspective dimensions). They enable to track changes and foresee structural problems (Allen et al, 2004). 3D models,

[3] http://en.wikipedia.org/wiki/Augmented_reality

[4] Virtual reality (VR) is an environment that has been fully simulated by a computer and perceived through electronic devices. VR is kind of immersive system, i.e. its user will have the impression that he is somewhere while, but in reality, he is physically in another place.

from a Digital City perspective, allow a much wider audience for 'virtually' tele-visiting a city.

– AR is also associated to Virtual Reality (VR) Technologies, mainly Computer Graphics, Context Aware Computing, Human Computer Interaction, Live Video, Motion Tracking Data and Machine Perception, etc.
– Developments of AR, and consequently 'Augmented city' approaches, have been, for the most part, influenced by the developments of Ubiquitous Computing (UC)[5]. UC aims to enable users to move around and interact with computers in a more friendly and intuitive fashion. The GPS (Global Positioning System) could be considered as one of the most famous examples of the application of Ubiquitous Computing. The main difference between AR and UC is that Augmented Reality pays more attention to the disappearance of conscious and intentional interaction with an information system than the Ubiquitous Computing does.

3.1 *HyperUrban as online augmented city*

Many projects have chosen Internet technologies to enhance potentials of AR applications.

(Papagiannakis, 2002) suggested a system based on a captured/real-time video of a real scene to explore the processes of narrative design of fictional spaces by being able to render realistic 3D simulations of virtual characters in real-time. This system offers its users a realistic interactive immersion experience.

3.2 *HyperUrban as wireless online augmented city*

Mobile technologies can profoundly enhance cultural experiences when exploring a surrounding city (Schilit et al, 1992; Sumi et al, 1998). Other realizations interconnecting a conventional museum to a surrounding city have shown special interest manifested by visitors with rich cultural experiences (Vlahakis et al, 2001, 2004).

3.3 *"Virtual City" as part of a its "reality"*

"City" is a multi layers "reality" embodying "present", "previous" and "future" realities. The 'present reality' one is complete on its own, regardless the physical condition and appearance. According to its incompleteness the present reality can trigger some perception and/or comprehension problems. In this regard, the 'previous realities' require more frequently to be reminded, to be said, to be illustrated, to be reconstructed and to be proved. The main aim of 'Augmented City is to add these elements of the 'previous realities' to the 'present reality' of a city, in order to allow a better understanding (feeling, living, etc.) of the city.

Understanding City has always being a multimedia task, even before the digital revolution. Images, schemata, inscriptions, engraving, sounds, etc. have always been the basic communication tools with city for both inhabitants and visitors.

By taking into account spatial and temporal constraints, some Mobile, Real Time Reasoning, Ubiquitous, Wearable and Wireless technologies have been considered to reinforce the Augmented City universe.

Augmented City is built upon the "real" world (as it is represented and/or digitalized) and incorporates VR elements. User (inhabitant or visitor) might put on translucent goggles or similar devices enabling him to perceive an augmented "real" world (considering present, previous and eventually future projects of the city) and to interact with it in real time.[6]

4 HYPERURBAN AS AN INTERACTIVE URBAN SPACE

An 'Augmented City Application' involves its user with both the 'real' and 'virtual' worlds in a spatial interaction paradigm. It is unlike VR interactions that immerse the users into a virtual world and thus replacing the real-world. It lets the user to see the 'real' world while seeing superimposed virtual information (for example 3D objects) that augments his or her vision of the reality.

The concept of HyperUrban embeds on itself a Human Computer Interaction (HCI) paradigm. Simulating part of the real world (part that most frequently perceived by a human being) can be used as an implicit input that will optimize the interaction domains (by reducing the interaction space). User can focus on a part of the real world (a viewed scene) which will stimulate the computer to generate a set of virtual information (uncovered by human senses) that can augment the human perception of the 'real' world.

We can distinguish at least two categories of users in an Augmented City (AC) context: inhabitants and visitors. Every user can belong to one or more of the following sub-categories: user (traditional) or Tele-user (distant-user) or V-user (virtual user).

In an AC context, traditional information management systems are very limited. Interactive highly friendly device can only establish dialog between users

[5] Ubiquitous Computing integrates computation into the environment, rather than having computers which are distinct objects. One of the goals of ubiquitous computing is to enable devices to sense changes in their environment and to automatically adapt and act based on these changes based on user needs and preferences (http://en.wikipedia.org/wiki).

[6] Azuma defined AR system as one that: 'combines real and virtual; is interactive in real-time and is registered in 3D (Azuma, 1997).

and city. It allows city user to see it through its temporal and spatial dimensions. Such system must consider the use of advanced ICT including GPS, AR, multi-modal interaction, Mobile Computing and 3D-visualization.

5 HYPEREURBAN: A CONTEXT-DRIVEN APPROACH

Augmented Reality does not augment the 'reality' but only suggests augmenting the perception of a given representation of this "reality". This perception or representation is limited to a set of information displayed through a Human Machine Interface paradigm.

Augmented City, as main piece of HyperUrban concept, corresponds effectively to this kind of systems where the Human Computer Interface displays a mapping of a given context. This mapping is closely limited to the capacity and to the number of available used sensors. Also, in this regard, the design of the HCI is of paramount importance to the usefulness of the augmented city that is built around: the appropriate representation of the knowledge about the city (and its different physical and historical layers) and the interactive visualization software. These complement abilities of the users, allowing them to interact intuitively with the purpose-built mobile and intelligent AC devices that appropriately handle vast quantities of data which includes (but is not limited to): computer generated 2D and 3D images, hand drawn sketches, notes, voice commands, etc. (Zreik and Beheshti 1998).

(Djenidi, 2004) argues that multi-modal human-computer interaction needs intelligent architectures in order to enhance the flexibility of the user interface. This will help the user of the city getting a broader spectrum of its "real", "distant" and "virtual" dimensions. The augmented reality provides a powerful and flexible user-interface and "intelligent" reasoning mechanisms (such like intelligent agents) for relating the 'real' world (captured) and 'virtual' world data (knowledge) (Lieberman and Selker, 2004). In this respect, the function of the "intelligent agent" is to search, retrieve and to store all information and knowledge about the "city".

(Dey, 2001) defines a context as 'any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. (Ryan, 1999) considers 'Context-aware computing' as an important aspect of ubiquitous computing (UC) in which the interaction with a computer is driven by externally derived or implicit context. Context in the AC covers an important number of conceptual and technological domains including context locating-awareness (GPS), context extracting, context understanding, context representation, context sharing, context data modeling, context data selecting, context data retrieving context data computing in real time as well as a lot of technologies and applications that are concerned with the sensing.

Modeling context is an experimental iterative process. A context is dynamic while it evolves into and together with its environment. It is absolutely time dependent and varies continuously. Following the human capacities of perception, this variation can be more or less perceived, once it has been captured or extracted, it becomes static and has to be represented by a fixed data structure like a model. In a different way a context maybe assimilated into a snapshot.

One of the main targets of extracting a context in the AC is to find out a set of more relevant data that need to be augmented. This looks like a sampling process in which context aware computing retains sequence of a signal that reflects, with more or less accuracy and reliability, a perception of a context ('reality').

6 HYPERURBAN: THE IUIMS CHALLENGE

Design process continuously generates new models. Rediscovering models generates some new or emerged concepts. AC problematic implies using and adapting the hottest technologies that will enable City users to explore "real"-distant-"virtual" information in real-time, i.e. an Integrated Urban Information Management System (IUIMS). IUIMS is a system that its value is increasingly recognized as an integral part of the design, planning and management processes of the urban area (the "City"). In the very near future, communication between city users (inhabitants and visitors) and city administrations will be mainly done through the IUIMS.

As we mentioned previously, IUIMS design is necessarily multidisciplinary project. It implies collaborations issued from the following disciplines (and not obligatory limited to): Architecture, Economy, Engineering, Ergonomic, Graphic Design, Human Sciences, History, Management, Philosophy, Politic, Technology, Urban Planning, etc. In practice those disciplines are represented by only tow nearly separated professional categories: Urban Planning and Information Technology Design (cf. figure 2), sharing very few common points (or disciplines)

Specifying and setting a IUIMS, in such conditions, is a big challenge that should bridge those separated disciplines and on the other hand put them into contact with the users (i.e. involving experts in ergonomic psychology and human sciences).

IUIMS design is the major challenge of HyperUrban. Specifying such a system is a fundamental and "complex" design and management problem.

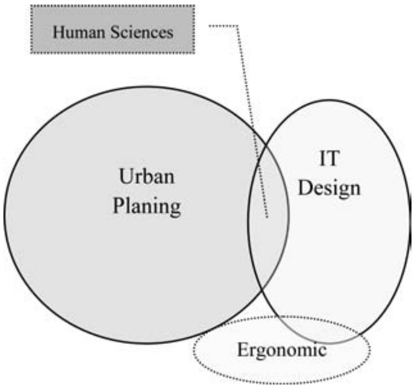

Figure 2. IUIMS design.

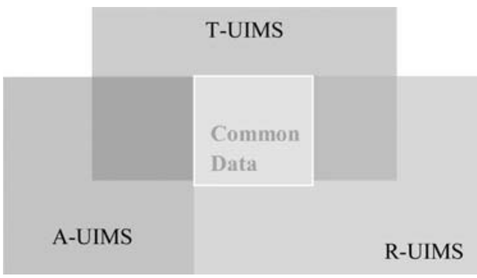

Figure 3. IUIMS sub-systems.

6.1 *IUIMS sub systems*

In HyperUrban's approach we distinguish three set of Practiced Contextual Information (cf. section 5), which could be ephemeral or not, to be considered as part of IUIMS: the in-vivo ("real") information, the distant information, the augmented ("virtual") information. Consequently, every IUIMS should integrate at least three sub Systems that can chair some common information:

– T-UIMS : Tele-city
– R-UIMS : In vivo - city
– A-UIMS :
– Augmented city (old and under layers city)
– Virtual city (city created on the net)
– Future city (city in project)

A multi-layered architecture is required. Specifying every part of this architecture and more accurately the set of shared data is highly complex due to the nature and the huge number of involved information.

As seen in figure 3, sub systems shard some specific data. This imply to:

– Set up a methodology allowing to recognize, retrieve and collect data related to each sub-system.
– Adopt a metadata approach
– Define a common data representation approach
– Select the common shared data

This vision of UIMS is very new. There is no appropriate methodology, neither validated method to tackle immediately the first step which is data identification and structuring.

The same level of complexity will be encountered when dealing with the problem related to information access and information retrieval trough IUIMS. This complexity will be increased by considering the different users and contexts categories.

What's more, user quality requirements have become fastidious: highly friendly, ergonomic, precision, recall, effectiveness; promptness …Thus a highly sophisticated Web IMS architecture has also to be ensured.

To define system requirements, data gathering and data analysis methods, HyperUrban suggests an experimental approach based on interactive attractive installations (artistic installations are very welcomed). It is important to remind that the technical part of this problem is much less complex than the conceptual part.

7 CONCLUSION "DESIGN BRIDGE APPROACH" FOR "INTEGRATED MEDIA CITY DESIGN"

This research project aims to define a methodology that can assist and bridge most professional categories involved in IUIMS Design. For this we have suggested the HyperUrban approach observing that urban environment is embodying new emerged forms and spaces of the "City" generated by the important development of ICT personal practicing (i.e. by the city inhabitants). Those new spaces invite to reconsider space and time perception within an urban environment.

HyperUrban postulates the shifting of the relation between the "City" and its Users (inhabitants or visitors). This fact entails the improvement of urban information management systems by considering tow additional concepts:

– the augmented city, to better understand the complexity of urban information system
– The Integrated Urban Information Management System to consider the merged form of social and professional urban environments.

In order to specify and develop an IUIMS, HyperUrban has chosen an experimental approach based on interactive attractive installation to get into communication with the "city" users.

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On AEC query formulation techniques

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ABSTRACT: A constantly growing amount of the AEC digital content calls for a better searchability. Once the content is indexed and search engines are in place, the searchability strongly depends on the end-users' ability to express what they are looking for. The latter is supported by query formulation techniques.

The AEC end-users will take a full advantage of the search engine if the user interface enables them to formulate queries that are expressive enough to match their specific information needs. Current search input interfaces often cannot provide means to formulate queries with sufficient expressive power. The paper gives an assessment of the existing query formulation techniques for the AEC information retrieval that reflects specific AEC content types and information seeking behaviour of AEC practitioners.

1 INTRODUCTION

The success of AEC information retrieval depends on its ability to support AEC information seeking behaviour and on searchability of the AEC content.

1.1 *The searchability of the AEC digital content*

Searchability denotes the ability to search content. The need for searchability increases with an increasing volume of the content and information about content (metadata). Furthermore, the searchability depends on document types, structure, format, and frequency of changes in the documents. For more details on searchability consult (Cerovsek 2008).

The AEC content volume. The volume of the AEC content is increasing with the digitization of old paper documentation, additionally new digital content is produced daily with digital devices and with engineering software tools for analyses, visualization and simulation. These tools enable faster production of inputs and therefore more digital outputs.

The AEC content types. A recent survey showed that typical building project documentation contains almost thirty digital file formats. Most indexers that are available for commercial search engines do not support many of those formats or they index only textual part of the document content.

The AEC content searchability. If we exclude indexing and searching issues, the most important factor for searchability is a query specification.

1.2 *On query specifications*

An exact query is an expression that enables a user to express with precision what he/she is looking for.

Table 1. Examples of the AEC queries and types of results.

#	Expected result type	Sample AEC query as question to be answered
1	REFERENCE	Which models have a similar layout?
2	REFERENCE	Which standards/projects are relevant?
3	REFERENCE	Which rooms have sunlight at 10 am?
4	REFERENCE	Which components have properties P?
5	REFERENCE	Which components are north from XY?
6	LOCATION	Where are buildings with green roofs?
7	LOCATION	Where is construction equipment E?
8	LOCATION	Where does material M come from?
9	MEASURE	How much material M is in the house?
10	MEASURE	How long is the longest span in design?
11	MEASURE	How long did it take to make a roof?
12	TIME	When did the material M arrive to site?
13	TIME	When did RFC for HVAC arrive?
14	PEOPLE	Who CRUD BIM entities last month?
15	PEOPLE	Who is competent for capacity design?

An AEC specific query specification should express: (1) what type and granularity of the content we need, (2) where the answer and content should come from, and (3) where to display the answer on a query.

Answers to the typical AEC query questions can be grouped into five main types: digital references, locations, measures, time and people (Table 1).

2 PROBLEM STATEMENT & METHODOLOGY

The main issue addressed in the paper is: "*How to improve searchability of the AEC content?*" to provide answers to sample queries given in Table 1.

This section sets some basic definitions needed for a common understanding of the paper and corresponding methodology.

2.1 *Definitions and problem statement*

There are three core IR components that support searchability: *crawler*, *indexer* and *searcher*. However, the paper is not focusing on them, neither on algorithms that enable crawling, parsing, analyses, indexation, and finally searching of documents. We assume that documents are completely crawled, optimally indexed, and the searchengine is perfect. The only problem we observe is the *query formulation*.

We assume that end-user should be able to formulate semantically rich and well-structured queries without in-depth knowledge about querying language, neither indexing structure, nor searching algorithms. A query can be either *explicit* or *implicit*.

In order to successfully formulate a query any end-user must be familiar with the content types that he/she is searching for. Typical examples of the AEC data are: textual documents (i.e. specifications), structured data (i.e. project databases), still-imagery (i.e. site images, CAD drawings), engineering models (i.e. BIM, structural models), audio and video data. These documents can be in several digital formats and locations. Different documents (and types) may contain answer to the same query and a document or its part can be index several times.

It is important to distinguish any physical digital document that is stored on a hard disk or on the web and a document in the search index. A search index document is equivalent to a single record in the relational database. Any search index document can have arbitrary metadata, which can be also computed, or extracted from the physical document. A search index document can also represent only part of the document, or several digital documents.

2.2 *Methodology*

The research methodology includes:

- Interviews on AEC information seeking behavior.
- AEC and computer science literature survey.
- Detailed problem definition and hypothesis.
- Prototyping and assessment of solutions.

The interviews. We started with seventy interviews addressing engineering information seeking behavior that occur during professional activities of AEC practitioners. The interviewees revealed a set of typical AEC query questions, as well as the information seeking paths and common principles they use to search, and use found information. The profiles of the interviewees were carefully selected and covered different organizational, professional and building project roles. The complexity of the query questions they would like to get answers from and the nature of the AEC information seeking behavior indicated the need to revise query formulation techniques to improve the searchability of the AEC content. This hypothesis was additionally supported with the literature and software survey.

The literature survey. The literature survey covered detailed analyzes of query formulation techniques in the light of specific engineering information needs and types of content.

This background research lead to the set of sample questions (Table 1) and to the high-level overview process related to query formulation (Figure 1). Both served for detailed studies of relevant issues, related to the AEC information retrieval. The paper is focusing only on the query formulation. Other aspects are beyond the scope of the paper.

2.3 *Paper structure*

The structure of the paper follows the structure, described in the figure bellow. Section 3 describes

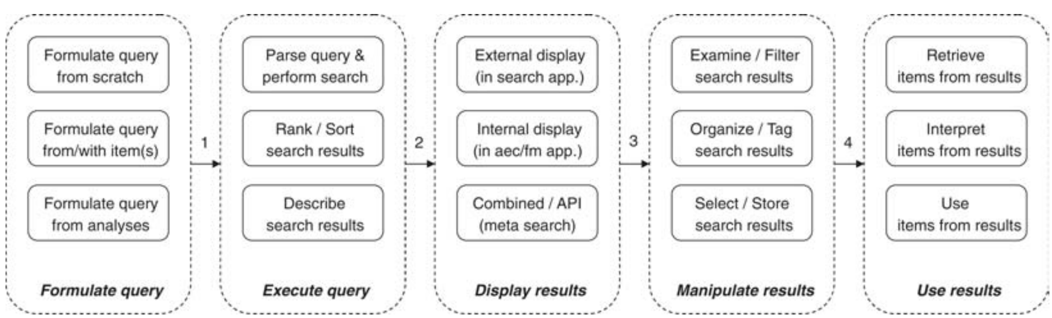

Figure 1. Query formulation part of the search problem represented by five boxes indicating five systems that interact with each other. (*the search process starts with a query formulation, constructed query is than processed, executed and results are displayed to the end user, and made available for manipulation and possible use by the end-users)*.

query formulation techniques, section 4 query execution and section 5 covers display, manipulation and use of results. Finally, section 6 provides an analysis and discussion on AEC specific query formulation needs.

3 QUERY FORMULATION

This section gives a more detailed description of the query formulation techniques. According to the number of and type of values a query can hold, we can divide queries to *discrete* and *range* queries.

A discrete query defines an exact value as an input to the querying process. With range queries we can specify sets, intervals, or sample representative and acceptable proximity measure that would still satisfy our information needs.

From the point of view of creative process, related to the query formulation, we can divide queries to three categories: (1) queries that are constructed from scratch, (2) queries constructed from existing items, and (3) queries constructed through analyses.

3.1 *Creating queries from scratch*

This category of queries covers all queries that are constructed without pre-prepared elements.

In everyday life we use human senses to find what we are looking for. In the physical world we are actually searching using all *five senses*. We *touch* the surfaces to find the material we are looking for, we also use *smell* to detect failures, or we use *taste* to find the food with the right ingredients. One of the most important senses for searching is our *sight*. We use sight to find items in the space around us. For example we visually inspect a bridge to find failures or we observe a facade to find ornaments we saw before. With *hearing* we are able to use our sound perception to find failures, for example by knocking on the floor we can detect tailing failures.

Humans also search through many other perceptions. They can search through perception of temperature (*thermoception*) we can find problems with isolations; through perception of orientation (*magneticeotion*) we can find a street, through pain (*nociception*) we can find painful spots on our body, etc. Some animals and devices are also able to detect many other natural or artificial signals and small differences in perceived measures of physical or chemical quantities. In the digital world we work, we have fairly limited capabilities. However, attempts have been made to integrate computers and human senses, such as sight, hearing and others.

Sight queries. There are several applications that are based on the use of eye movements that is in IR relatively new approach. In (Maglio and Campbell 2003) they introduced a prototype attentive agent application which monitors eye movements while the user views web pages, in order to determine whether the user is reading or just browsing. If reading is detected, more information of the topic is sought and displayed (Hardoon 2007). Sight queries are also extremely important for augmented reality and machine vision applications (Murray 1987).

Hearing queries. Most of the interfaces operate on the bases of speech to text conversions (Johnson et al 1999). There are also several speech friendly search engines, which allow us to express search queries via sound input. A simple example of a speech query is nowadays common and integrated in almost any cell phone. Speech recognition systems do not use audio digital format as input to search directly, but convert speech to text and use text as a query. A set of more sophisticated methods were developed for the synchronization of sound and symbolic data, for automatic analysis through perceptual rules, and for computing a “transportation” distance for the comparison, modelling of rhythmic motifs, of melodic traits, and of cognitive distance, together with metrics (Hewlett & Selfridge-Field 2005).

A query can be formulated through any standard computer input device, through specialized software programs, or through external sensors or specialized devices that are attached to the computer.

A query can be anything that is stored in a format readable by the computer system. Here we are especially interested in those formats that can store typical AEC data.

Text queries are the simplest form of queries that are still most frequently used. Text queries can be divided according to the syntax into two groups:

- Natural language syntax. Text queries that are based on natural language queries use the syntax that is common to a specific language. Such text should be morphologically, lexically, syntactically, and semantically analyzed.
- Querying language syntax. These queries comply with a specific querying language (i.e. SQL) and the syntax must comply with agreed rules.

Still-imagery queries include both, raster images and technical drawings. There are two main types of queries:

- Free-hand sketches. Free hand sketches can be used to find humans on photographs (Jianzhuang, & Xiaoou 2005) to retrieve 3D models based on characteristic views (Mahmoudi & Daudi 2007) and (Hou & Ramani 2008).
- Primitive based sketches. Such an interface would enable an end-user to construct a query through the use of graphical primitives or components.

We can further divide queries according to content type that can store formulated query: text, still-imagery, models, sound, audio and video and other sensory data. A similar procedure presented bellow, can be used for other content types.

Recently a lot of attention is given to the search of shapes. A complete overview of shape searching techniques is given in (Iyer et al 2007).

3.2 *Creating queries from or with items*

If we want to find a specific building component that we can easily describe with words – either due to complex technical or geometrical properties – it is often easier to use a representative item and try to find matching items. This is only possible if the search engine supports similarity based queries. This similarity is usually expressed through the distance measure that can be either discrete or continues. For example we could select one item and depict those properties we want to have in the item we are searching for.

This problem is similar to the question #1 from Table 1: "Which models have a similar layout". If we don't provide a sample model, the only reasonable result would be groups of similar models. A query formulation from items would be either based on a sample model with layout, or end-user would be able to construct a layout from layout elements.

An example of such a query can be also formulated from a set of symbols that represent concepts. Another example is query by spatial icons (QBSI), which formulation is a unique visual query language to explicitly specify concepts the user is searching for, but are hard to explain using keyword. The system allows to spatially locate typical contents on a blank canvas. Similar, simplified commercial visual search solution like oSkope, eVision, pixLogic present to the end user a set of images that acts as visual search assistant to search images on different sites.

In the context of AEC such query formulations could be significantly improved the search experience. It would simply allow users to select a set of typical building components or other features that define information needs.

3.3 *Creating queries from analyses*

Queries based on the analyses use collective intelligence (Segaran 2007) or use clustering techniques that allow them to group items automatically.

Collaborative filtering is a method of making automatic predictions (filtering) about the interests of a user by collecting information about interests from many users (collaborating). Recommendation systems are programs which are often used in e-commerce services: they process a dynamic user's profile to predict items he may be interested in. Often, they are implemented as collaborative filtering algorithms.

Predictions are specific to the user, but use information gleaned from many users. Filtering techniques can be usefully applied to very few categories where a single person can make relevant choices. Many commercial web sites adopt collaborative filtering techniques (i.e. Amazon.com users who bought also bought), or enable predictive modelling and other artificial intelligence techniques.

4 QUERY EXECUTION

This section provides an overview of the query post-formulation part of the querying process. This processing starts after the query is formulated and received by the search engine. In the following subsections we first review parsing procedures, then query execution, ranking and representation of the results.

4.1 *Parse query and perform search*

Once the query is formulated and submitted to the search engine, it must be pre-processed before the search can be actually executed. Two main steps are required before searching takes place: (1) the query must be parsed, and (2) the query must be mapped into internal query syntax that is understood by the search engine. Query parsing is as such mapping from one vocabulary to another.

The complexity of parsing and mapping depends on the type of input (formulated query content type and syntax used) and targeted query format (internal querying language syntax). If we observe main input types, we can group them into four categories: (1) natural language queries, (2) semi natural language queries, (3) specific query languages syntax and (4) non-textual queries.

Natural language. Natural language queries are the same as we use them in spoken, every day language. Therefore, a conversion into internal query formulation must be supported with natural language processing techniques that enable software to reveal meaning from natural language statements. This process includes morphological, lexical, syntactic, semantic and discourse analyses. Typical examples of services that use natural language include services like AskJeeves. The form of question from Table 1 all fall into the category of natural language.

Semi-natural language. Many general search engines claim that they use natural language. However, they do not use natural language, but agreed syntax that is very simple compared to querying languages.

Querying language syntax. Depending on the type of content we want to query, different logic is available and supported with querying language. The most known querying language is SQL is a standard interactive and programming language for querying and modifying data in databases. To query spatial data new operators are needed. Such spatial operators operate on spatial data types and possess spatial semantics. They can be classified into: (1) directional operators (such as above, below, northOf, southOf); (2) topological operators (such as touch, contain, equal, inside) (3) metric operators (such as distance) (4) Boolean operators (such as union, intersection) (Borrmann et al 2007).

Non-textual queries. The mapping of this type of queries requires complex representations that are also used for shape searching (Iyer et al 2007).

4.2 *Query results ranking*

It is important to distinguish sorting, ranking and grouping. All of them are related to the order of the items that are listed in the search results. Sorting is defined by field name, and ordering. Such an order may not be relevant. Ranking on the other side implies that the results should be presented in an order that is relevant to the end-user. Ranking also requires some pre-processing before the results are returned.

Typical ranking algorithms either compare terms and their frequencies in formulated query and in the search index, or they use more advanced algorithms that try to determine relevancy (Segaran 2007). The most simple content-based rankings take into account simple frequencies of query terms in words and query terms in documents, additionally ranking can also take into the location of query terms in the physical document, or in a case of multiple terms in a query, the ranking mechanism can also take into account the proximity of the same sequence of terms. The Google PageRank algorithm calculates the rank (PR) of a page A on the basis of citations: $PR(A) = (1 - d) + d\,(PR(T_1)/C(T_1) + \ldots + PR(T_n)/C(T_n))$, where T_1, T_n are pages that point to A an d is factor. Which ranking algorithms can be used in AEC?

4.3 *Description of query results*

Once the documents in the search index are matched against the query, they must be properly described to motivate users to select particular item from the search results. The description strongly depends on the device and software that display the results.

Usually, search engines use parts of found documents. Many search engines provide extracts from the page as a description. But, studies say that extracts from pages usually do not serve the cause. A page is often described by other pages better than by itself, therefore they developed algorithm, which retrieves descriptions about a page from those linking to it and ranks them (Deepak & Jyothi 2004).

Although the concept is applicable to AEC, it is important to note that the display of search results on the web assumes availability of unique identifiers for each found items (URL), title of the document, and possible several other metadata.

In a case of AEC content types, many of enumerated features are not available. For example, there is no identity of the layout, only a whole building that is described in the model, neither there is a simple way to uniquely identify and describe other concepts. Therefore AEC information retrieval should answer to questions like:

- What makes a resulting document/part unique?
- What represents the identity of a document/part?
- How to provide description of the matched item that has no metadata or textual descriptions?
- How to describe a set of non-textual items?

5 QUERY SEARCH RESULTS

This section provides an overview of possible ways that can be used to display search results. There are three crucial issues related to the display of search results: *when, where,* and *how*. The answer to the first two questions is given in section 5.1, while the answer the *how* questions is given in 5.2. Section 5.3 describes *what* we do with items from the results.

5.1 *Display of search results*

Depending on the time needed for the communication between end-users interface and search engine we can make a time-wise division of the display of search results to *synchronous* and *asynchronously*.

Once the query is constructed it is submitted to the search engine that returns results which are then processed and displayed to the end-user. A synchronous display of the search results implies interaction with an end-user in real-time – usually in less than a second, exceptionally within a couple of seconds.

Asynchronous display of the search results is typical for complex searches or agent technologies. A typical search agent communicates with end-users via email or any other similar asynchronous communication system (i.e. IM). The display of results can contain either groups or individual items.

The location-wise classification of the display of results in terms of "digital place" we can divide display results to in: (1) an application that is specialized for searching, (2) application or (3) search based on search API.

5.1.1 *Display in specialized search application*

The search results displayed in the application that is dedicated to searching are usually very well organized. Such an interface can support several views on the content. For example in Google we can display results in list view, info view, timeline view and map view. Many applications of this concept could be used in the AEC context.

5.1.2 *Display of the search results in AEC/FM app.*

A typical example of the search facility that is integrated within office or AEC/FM application, is usually accessible through CTRL+F, which invokes FIND dialog box. A bit more advanced search feature is available in Adobe Acrobat, but most engineering applications do not support searching, or only part of textual data is searchable, however the applications do not support advanced features.

5.1.3 *Combined/API based display of search results*

This way search results can be aggregated and integrated into applications that does not originally support any type of search. API could be also used to integrate searching of items from physical world in the digital world.

5.2 *Manipulation of results*

The main goal of the mechanisms that enable end-users to manipulate results returned from the search engine is to support them in information seeking.

The goal of the end user interface is to exploit as possible end-users' ability to improve his searching ability and not only technical abilities of computer representations. Several studies have shown that the quality of search results significantly improves with the availability of multiple querying techniques.

5.2.1 *Examination and filtering of results*

The way the results are presented to the end user is usually defined through different visualization techniques. Visual display of interfaces has been a popular research topic in recent years. Different paradigms have been used to represent search results. Results can be represented textually, graphically or both. There is a plethora of visualization techniques that are often enriched with the automatic categorization, colorization, clustering and search customization techniques.

The most frequently used features in visualization techniques are: the use of icons to represent concepts, the use of colour codes and textures to indicate results differentiation, tree maps to represent similitude, zoom function, animations, projections to two, three or hyperbolic dimensions.

In the building project context tree maps were suggested as a tool to help AEC practitioners to find relevant information. Demian & Fruchter (2005) demonstrate the solution that is based on a corporate repository where knowledge is captured and presented in the context in which it was created, e.g.: rationale, evolution, project environment and multidisciplinary perspectives.

Autodesk.Seek is using control vocabularies (CSI MasterFormat 2004, omniClass and UniFormat) to filter out search results. Each searchable item has assigned category and set of searchable properties. For each category from the controlled vocabulary it displays a manufacturer, file type and links to external catalogue and specific product libraries.

5.2.2 *Organization and tagging of results*

Tagging systems have become increasingly popular. These systems enable users to add keywords (i.e., "tags") to Internet resources (e.g., web pages, images, videos) without relying on a controlled vocabulary (Marlow et al 2006). Tagging systems have the potential to improve search, spam detection, reputation systems, and personal organization while introducing new modalities of social communication and opportunities for data mining. This potential is largely due to the social structure that underlies many of the current system. Many online services enable customizable organization of the results.

Social tagging systems, as we refer to them, allow users to share their tags for particular resources. In addition, each tag serves as a link to additional resources tagged the same way by others.

Because of their lack of predefined taxonomic structure, social tagging systems rely on shared and emergent social structures and behaviours, as well as related conceptual and linguistic structures of the user community. Based on this observation, the popular tags in social tagging systems have recently been termed folksonomy. For details consult (Marlow et al 2006).

5.2.3 *Selection and storing hits*

There are several mechanisms provided by many online services to allow storing of hits. The most common include the possibility to save formulated queries with history (www.sciencedirect.com), more advanced services also enable end-users to store results and later on compare the differences in the results to the same query, but at different times.

5.3 *Using results from search*

The relevancy of the search results depends on the quality of formulated query. Recall and precision are common measures to measure usefulness of the results. The item from the search results that end-user can really use for the professional work is really relevant. The fact that one item was selected from the search result does not prove its usefulness.

5.3.1 *Retrieving items from results*

There are two actions that effect relevancy of search results cloaking and redirection. Cloaking is the practice of sending different content to a search engine than to regular visitors of a web site. Redirection is used to send users automatically to another URL after loading the current URL. Both techniques can be used in search engine spamming (Wu et al 2005). On the other hand redirection is also used by the search engines to detect hits that were selected by end-users, which helps them to improve results.

5.3.2 *The interpretation of items from results*

The interpretation of the results may generate a need for additional queries that could help to interpret results. The interpretation can also be supported with different views of the same search results. Many commercial search engines already support an automatic identification of concepts.

5.3.3 *Use of items from the results*

The use of items that were displayed in the results of a search is the final evidence that the query was formulated correctly and returned "use"-full results. This fact should be taken into account for final determination of the recall and precession factors.

6 ANALYSES AND DISCUSSION

The first part explains types of queries (section 6.1) and how they are build, while the second part (section 6.2) addresses carriers of the queries. Subsection 6.3 gives an overview of applicable approaches.

6.1 *Query building techniques*

There are four main query formulation techniques:

Query by Syntax. The syntax describes how language grammar is used. A syntax can describe how words, symbols or morphological sounds are combined together to be properly understood. Any language that is used in information retrieval must follow some syntax to be properly interpreted. In general we have two syntax types that can be used by search engines: sequential and non-sequential. For example if we use graphical symbols (like diagrams) in a formulated query, a query does not need to be interpreted sequentially.

Query by Example. A query by example was an early invention in database design and evolved further a widely adopted concept. It can be successfully applied to any type of AEC data, regardless indexing or database structure.

Query by Template. Query by template is a well established in digital libraries. An important feature of query by template is that it implies the use of a graphical representation (Arijit & Andrew, 1997). The concept of query by template is especially useful when the document does not have a predefined, well known data model as well as it can be used to query only parts of the documents.

Query by Co-occurrence. Query patterns are created whether through collaborative filtering or through other co-occurrences that are either determined through content or through information seeking activities.

6.2 *Query carrier*

From the perspective of query content representation we can divide queries to:

Text queries. Query by text is one of the most common query formulation techniques. Queries can be directly typed using keyboard, transformed to text via speech-to-text transformation, and from many other formats. Text queries can be formulated in a natural language or in specific querying language (i.e. SQL, XQuery, SQL, SQL3, etc.) Text based query formulations are well established and support Boolean model, hierarchical querying, proximity searches, and spatial queries.

Still-imagery queries. Many engineering content types cannot be represented by text. Many informaton needs without graphical representations. There are three main graphical representations that must be explored: raster graphics, vector graphics, and object oriented graphics in the context of AEC content. The querying by still imagery is either based on graphical query authoring environment, as well as it can be additionally supported with images that either serves visual assistance or provide iconographic searching, which represents concepts we want to find.

Modelled queries. Modelled queries are an evolving approach that is currently not widely supported. An example in engineering practice would be a simplified modelling tool that enables quick modelling of principal characteristic of searched items.

Video quires. A video as an input for query is rarely used concept in the information retrieval. The use of video queries is relevant when we want to find a wider sequence of video, animation or simulation or if we are looking for similar videos.

Sound queries. Sound based quires explicitly refer to the input recorded with microphone or represented by any kind of wave sound file format. A recorded sound sequence can be compared against stored audio files using metric methods.

Sensor/Device data queries. Sensory data includes both physical and chemical quantities that are not a sound or a result of physical effect. Query is captured and actuated by a device to serve as query.

Combined queries. Combined queries are quires that include a combination of above mentioned quires. Combined queries are also needed for searching across several indexing structures.

6.3 *Applicability of querying techniques*

Table 2 gives an overview of querying formulation techniques by type of content.

Table 2. The review of applicable query formulation techniques.

	AEC content type				
	Text (i.e. building codes, specifications, contracts)	**Structured data** (i.e. quantity survey data, change orders, payroll records)	**Still-imagery** (i.e. elevations, shop drawings, technical drawing specs)	**Engineering formats** (i.e. structural models, BIM models, gis data)	**Audio and Video** (i.e. on-site images, time laps video, meeting minutes recs.)
Questions that can be answered from content type					
Table 1 Query #	2,8,13,15	2,9,14,15	2,7,10–12	1–6,9,10	7,8,10,12
Type of query to be used to find AEC content type					
Q. by Syntax	X	X			
Q. by Template	X	X	X	X	
Q. by Example	X	X	X	X	X
Q. Co-occurrence	X	X	X	X	X
Type of query carrier that can be used to find query					
Textual query	X	X	X	X	X
Still-imagery q.	X		X	X	
Video query	X		X	X	X
Sound query	X			X	X
Sensor data query	X	X	X	X	X
Combined query	X	X	X	X	X

7 CONCLUSIONS AND RECOMMENDATIONS

General remarks:

- The key to the improvement of the AEC IR is in in-depth understanding of the engineering work, and engineer's information seeking behaviour.
- Engineers will use the information that was retrieved by the search facility only if they understand the context.
- User interfaces must support AEC users by further guidance if there are no or if results are bad.
- An AEC user should be able to search and get results on different granularities from project data.
- Engineers should be able to display results in their models, as well as parts of models should be searchable and displayed independently.
- Engineers should be able to display the same results through different views, including within AEC/FM applications and different rankings.

The following general recommendations regarding the query formulation techniques can be made:

- Query by Example and Query by Template are very promising, but not exploited the in AEC IR.
- Query reformulation should follow iterative nature of AEC information seeking behaviour.
- Multiplicity of document sources and types also requires multiple query formulation techniques.
- AEC end user should be able to combine queries, for example queries by example and text queries.
- End-user should be able to improve results by gradually improving recall and precession.
- The AEC content that doesn't depend on a language should be searched by queries. Non-textual content should be also supported with non-textual queries. Examples include searching by sketching, drawing, or modelling.

In order to support a trans-national nature of the engineering profession it is important to support multilingual information retrieval. This includes:

- Multilingual query formulation process. For review of approaches consult (Oard 2002).
- Multilingual field content and metadata data model should enable formulation of queries in multiple languages.

The use of an AEC specific controlled vocabulary like (Davidson et al 1978) could significantly improve searchability. Vocabularies should be used to:

- Support searching process with consistent and clear hierarchies for browsing and filtering as well as serve as query expansion mechanism.
- Improve to properly interpret technical language, since terms can have completely different meaning in the AEC context.
- Support indexing. Improve searching of non-textual content by providing values for the metadata about AEC data.

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Semantic annotation and sharing of text information in AEC/FM

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ABSTRACT: Text integration denotes the integration of unstructured text content with corresponding structured information resources. It can be considered a two step analyses in which text content is first of all externalised and then interrelated with corresponding model-based information. However, the effectiveness of text technologies for the automatic externalisation of text information greatly varies with the type of documents and the available background knowledge. Hence, a semantic service environment named COnstruction PRoject Information MEmory (COPIME) has been proposed that allows for flexibly combining text technologies and utilising available project context information. Backbone of the environment is the *Construction Information Resources Sharing Ontology* (CORSO) that captures context knowledge from structured project resources, general knowledge about the available text technologies and language resources as well as the text information extracted in the document analysis. The paper introduces the overall system and describes the individual steps of the document analysis. Furthermore, the design of the CORSO ontology is introduced that represents an upper ontology defining the basic concepts of the ontology repository. Finally, the paper reports on a preliminary study on metadata standards that have been reviewed in the course of detailing the CORSO ontology for its validation on real-life construction documents.

1 INTRODUCTION

In distributed project organisations there is a need for integrating independent and self-contained text information with centrally managed project data. Even with an increasing utilisation of design, engineering and controlling systems, a multitude of text documents such as contracts, expert's reports and emails will prevail in natural language text. Moreover, with a shift from traditional document based information exchange to computer integrated information sharing, more and more decisions will be affected by separated information processes. Decision makers must be enabled to easily consult relevant information of both computer accessible as well as self-contained unstructured information resources to identify redundancies, consider and respectively solve inconsistencies.

This text integration first of all requires the externalization of the most relevant document content and is thus most often considered an information retrieval or mining problem. However, in the context of heterogeneous project documents the effectiveness of retrieval or mining technologies greatly varies with the documents' focus and the availability of background knowledge. Moreover, recognised information also needs to be effectively distributed among the different project participants to support information and knowledge sharing across all teams and disciplines.

Hence, the objective of our research is not to develop yet another search or mining algorithm, but to establish text technologies within collaboration environments, which can be most flexibly combined to automatically structure, extract and share text information in accordance to critical integration tasks and the available linguistic, industry and project knowledge.

An architecture for text integration has been proposed that combines several components for the analysis, processing and integration of heterogeneous information resources. Overall the integration process comprises two subtasks, i.e. the analysis and externalisation of a documents' text content (document analysis) and the distribution and reuse of the recognised information (text content sharing). Backbone to the approach is an ontology repository that is used in two ways:

– Firstly, it provides a knowledge base of common concept definitions, terminological aliases and background knowledge to support semantic annotation, extraction and mapping of information from different resources.

– Secondly, it represents a central repository for storing and consolidating semantic information from heterogeneous resources as well as to support different query and retrieval technologies.

The paper introduces the overall system and particularly describes the different steps of the document analyses. Furthermore, the design and utilisation of the *Construction Information Resources Sharing Ontology* (CORSO) that represents an upper ontology defining the basic concepts of the ontology repository is introduced. Finally, the paper reports on a preliminary study on metadata standards that have been reviewed for the detailing of the CORSO ontology.

2 TECHNOLOGIES FOR TEXT INTEGRATION

A semantic service environment named COnstruction PRoject Information MEmory (Coprime) has been proposed that combines several components for the analysis, processing and integration of heterogeneous information resources (Schapke et al. 2006, Schapke & Scherer 2006).

Central to that environment is the *Information Resource Sharing and Integration Service (IRIS)* to control analysis and integration processes as well as to consolidate the relevant information from different project resources. For the analysis of text documents it coordinates two subsidiary services, namely the *Text Document Store (TED)* that collects copies of the distributed text documents and various linguistic resources as well as the *Semantic Text Analyses and Annotation Service (STAN)* that encompasses several text technologies for the documents' analysis.

Backbone of the IRIS Service is the CORSO Ontology. It represents an OWL-based repository that captures the project context knowledge from structured project resources and linguistic knowledge about the available text technologies and language resources. Secondly, it stores the information extracted from the project documents supporting further information consolidation, retrieval and distribution.

To coordinate the overall integration process the IRIS Service relies on user-defined *Integration Scenario Definitions* (INSIDE) that specify the configuration and orchestration of the text analysis components and the respective linguistic and contextual resources as well as the later utilization of the discovered text information.

To demonstrate and further examine the potentials for combining text and semantic technologies, prototypes of the described services are being developed. The following two sections describe the functionalities of the implemented analyses components and the ontology repository in more detail.

2.1 *Text document analysis process*

In general we can distinguish three levels of complexity when analysing the content of text or multimedia documents (Mitschick et al. 2008):

– On the *first level* structured data, like the format and size of file, the duration of a video or the font of a paragraph can be extracted from a document and its metadata. Typically these low-level features can be stored in multidimensional vectors providing comparable or scalable measures.
– On the *second level* implicit features of a document are discovered, such as a pictures' motive or a texts' topic or key phrases. Typically, pattern recognition and classification techniques are used to extract or derive these features from the content.
– On the *third level* information on the documents' context, such as the role of a document in a business conversation or the author's intentions, is demanded. In addition to the documents' features this context analysis may obviously require additional background information and user feedback.

In the Coprime environment the first and second level analyses are performed by the STAN Service that is implemented based on the General Architecture for Text Engineering (GATE). GATE represents a Java-based framework for developing language engineering applications that readily provides central control components to build and run text analysis pipes as well as some common text processing components (plugins) accessible via a common API.

Figure 1 illustrates the five steps of the overall document analysis and knowledge integration process as well as the respective interactions among the IRIS, STAN and TED services.

The first step *resource configuration* is used to import the distributed text documents. Moreover, project specific language resources are built from the CORSO ontology specifying names of e.g. persons, companies and products as well as respective naming conventions used for labeling plans, work packages or minutes. It is notable, that these project specific language resources distinguish the approach from other text mining and retrieval systems that mostly rely on general linguistic knowledge and maybe a few domain specific lexica or thesauri.

The second step *text preprocessing* represents a common text analysis preprocessing pipe. It comprises a tokenizer, a sentence splitter, a stemmer, a part-of-speech tagger and an orthographic coreferencer that have been adopted for German text. Using the GATE document model the analysis results are stored in separate attributes within the documents instead of inline text annotations.

The *content analysis* in the third step comprises three different tasks for extracting information from (a) structured metadata as well as

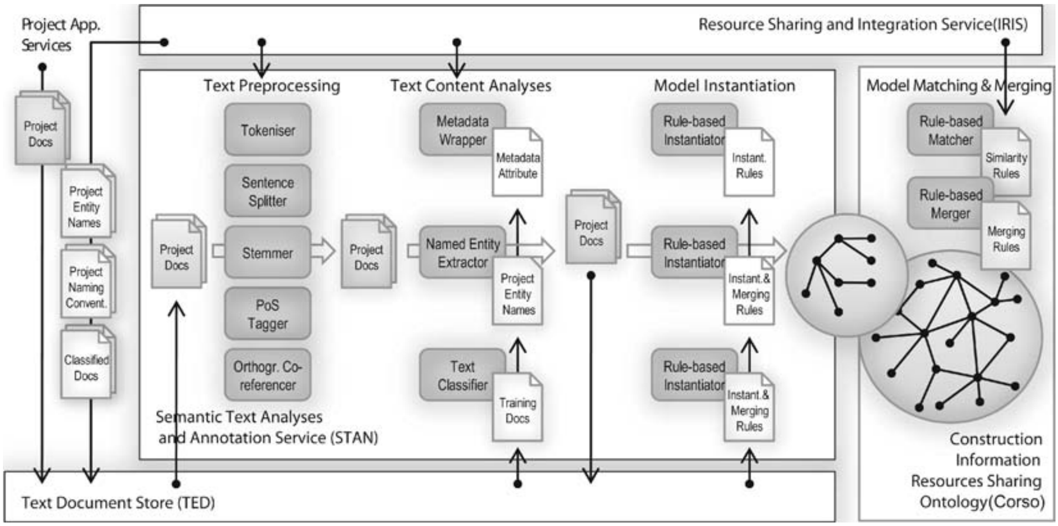

Figure 1. Taxonomy of the Construction Information Resources Sharing Ontology (CORSO).

form (b) unstructured text content as well as for (c) classifying the documents' content. Metadata annotations can be readily wrapped during the file import based on the given schemas (e.g. dtd) or respective filters (e.g. email).

The named entity extractors are built using the Java Annotations Pattern Engine (JAPE) of GATE that provides for rule-based information extraction from the documents' content. The current rule basis comprises a bibliotheca of both lists with general and construction-specific domain names of e.g. materials, codes and measures as well as regular expressions for text patterns of e.g. scales, addresses and building codes. Moreover, project specific resources with person and company names as well as text patterns e.g. for room numbers such as "Biblothek-1.17-K5-33" have been developed from an exemplary project documentation.

Finally, text-based classifiers are trained to generate additional metadata for the overall document and some of its sections. The main goal of classifying the documents' content is to gain additional information on the document's function, e.g. its role in a particular business conversation or at least its basic type of speech act, e.g. request or offer (cf. Caldas & Soibelman 2003, Cohen et al. 2004).

In the fourths step *model instantiation* a temporary ontology model is generated for each document to harmonise the extracted text information. Ontology instances are created for metadata attributes and named entities using JAPE rules that are complemented with executable Java code. The decoupling of the text analyses and the model instantiation first of all provides for the reuse of common text extractors and language resources. Moreover, it allows pattern-based combination of different entities into nested objects and their interrelation via reoccurring entity names.

The fifth step *model merging* finally concerns the integration of the extracted text information with the central project knowledge. Unlike the preceding steps this task is performed by the IRIS service. IT is based on the Jena Semantic Web Framework that provides advanced reasoning support for the consistent management of the OWL repository (Carroll et al. 2004).

Ontology constraints and axioms can be used to detect semantic errors in the models as well as to automatically (re)classify newly extracted text entities. However, the partially incomplete and error-prone data sets generated by the document analysis limit the possibilities of enforcing model integrity. Hence, model consolidation will be performed running separate model analyses to integrate the new model instances. As described in Mitschick et al. (2008) it is planned to deploy Jena rules using builtin primitives for pairwise semantic similarity analyses. The successive merging of matching instances is described in the following section.

2.2 *Construction information resources sharing ontology*

Generally speaking, the Construction Information Resources Sharing Ontology CORSO represents a collection of context information on the overall project. Based on the notion that this information stems from different information resources of varying detail, structure and trustworthiness, the main purpose of the ontology is to collect, interrelate and consolidate the collected information to support further information validation, retrieval and analysis.

In project documents various incomplete descriptions of the same things are used that cannot always be completely interpreted and interrelated. Unlike work specifications and product models that reflect one particular view and status of the project, i.e. the anticipated physical project results, common project documents are also concerned with the various physical and non-physical resources and their utilisation to achieve these results. Moreover, practitioners use different conceptualisations of these entities, and there are numerous possibilities to refer to them in natural language text.

In the CORSO ontology we first of all address these issues by a trichotomy of classes on the uppermost lever, distinguishing:

- *Construction Project Realm Entities* (Core Ontology) representing all real-life entities of construction projects,
- *Project Entity Resources* (Entry Ontology) referencing the original resources that specify the Core entities,
- *Project Entity Representations* (Peer Ontology) providing general background knowledge how core entities can be described.

While the Entry ontology in fact represents a submodel of the Core ontology capturing up-to-date project information, the Peer ontology stores general linguistic knowledge for the time of the project and beyond. The following two sections introduce the main design decisions for these ontologies.

2.2.1 *Core and entry ontology*

Although numerous research discussions in the area of product modelling have shown that it is merely impossible to develop and respectively agree on an overall model of construction projects, the Core ontology nevertheless requires a holistic perspective on AEC/FM collaboration.

A very comprehensive project ontology has been proposed in the e-Cognos project that takes a process centred approach to describe all the relevant aspects throughout a construction projects process (Lima et al. 2003). The major domains of its taxonomy are *Actor, Product, Process, Resource, Technical Topics, Project* and *Systems.* While the first four domains are basic entities of collaboration in most enterprise and engineering models, the domains five, six and seven provide for the representation of different conceptualisations of these aspects in different technical and disciplinary contexts. However, so far the complexity and sheer size of the ontology has hindered the consistent concretisation and application of the model in practice.

To retain a manageable repository, it was decided to only define an upper knowledge structure for the CORSO ontology that can be extended with most important domain concepts and linguistic knowledge in accordance to the most relevant integration tasks of the users.

Starting point of the ontology development was the DOLCE upper ontology that universally describes things of our world from a perspective of human cognition. It formalizes general notions of things such as physical objects, processes, events, time and space. Advantage of this approach is first of all the adoption of a theoretically well-grounded and extendable superstructure. Class and property definitions in DOLCE follow uniform classification principles so that extracted entities can be classified into more general classes if detailed properties cannot be distinctively identified. Systematic property definitions and fundamental class restrictions assure the generation of meaningful models.

Moreover, the cognitive view on things quite well resembles the perspective of natural language text. The following paragraphs discuss key characteristics of the Core taxonomy depicted in figure 2.

Firstly, the separate conceptualization of qualities provides for classifying isolated text entities, such as addresses, scales or material requirements. In engineering models these qualities are often considered properties that cannot be instantiated without respective objects. Similarly, the separation of *core:ProductFeature* and *core:Substance* from the *core:Product* allows for the independent representation of intrinsic and uncountable objects such as “window whole” or “mortar”. For the evaluation of the research prototype such isolated text units can be manually interrelated to form complete information objects. For future applications further research will have to be conducted as to how text chunking and coreference analyses as well as ontological context analysis can be successfully used to automatically interrelate and merge the respective instances.

Secondly, the Core ontology provides for the specification of instances in regard to different contexts. Particular the class *core:state* allows for the definition of object properties in prevailing situations such as general project stages that are not bound to a certain *core:processes* or *core:events*. Moreover, we can distinguish various social contexts indicated by the *core:role*, *core:system* and *core:KnowledgeArea* in which agents and objects can occur. In the context of text integration this does not only provide for the definition of different conceptualizations but also for capturing diverging entity specifications due to different viewpoints and alternative solutions or incorrect construction realisation.

Thirdly, to support the consolidation of the project information the ontology captures instances with

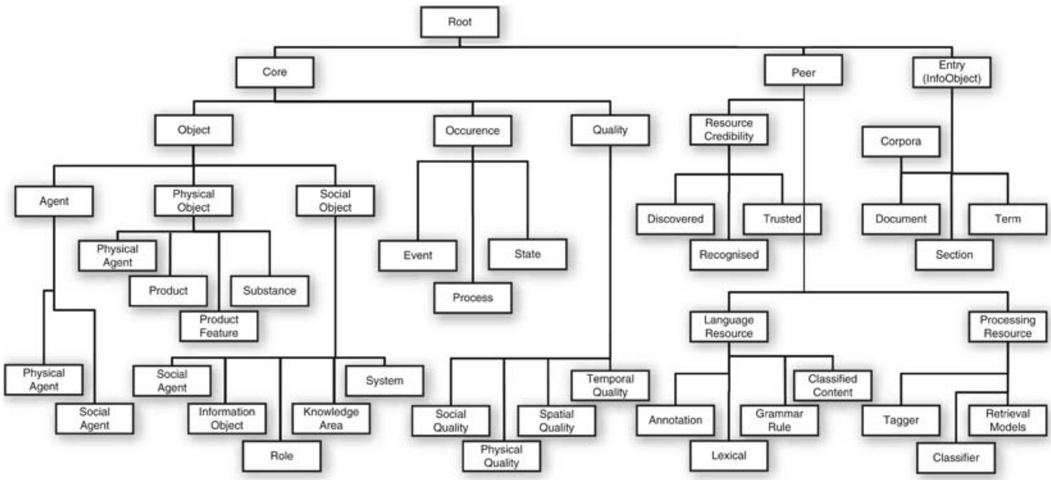

Figure 2. Cor text document analysis process.

respect to their originating resource as well as its identification process. Matching analyses can be performed calculating semantic similarities considering orthographic coreferences (cf. Mitschnick 2008). Duplicates without conflicting properties can be merged to one instance. All others can be interrelated by owl:sameAs. However, for the identification of extraction errors, diverging conceptualizations or just different states of the entity further analyses and user feedback will be required.

2.2.2 *Peer ontology*

The project entity representation ontology (Peer) is used to capture knowledge on the different forms used to represent construction entities in information resources, i.e. particularly natural language text. This linguistic knowledge is used to support the build-up of text analysis pipes within the STEN service.

As depicted in figure 2 the top level of the Peer ontology comprises three classes to distinguish language resources and processing resources as well as to classify their credibility. In regard to the processing resources we only distinguish among *peer:Tagger*, *peer:Classifier* and *peer:RetrievalModel* based on the basic technology of the different text analysis components and their results.

The corresponding language resources are first of all classified by *peer:Annotation* capturing attribute names of metadata schemata and respective linguistic annotation schemes as well as *peer:Lexical* subsuming single terms and n-grams of core entities. Linguistic knowledge for particular text analysis components is represented by *peer:GrammarRule* subsuming deterministic rules of taggers for tokenising, sentence splitting, stemming, POS-tagging and orthographic coreferencing. Finally, the class *peer:ClassfiedContent* provides annotated documents used for training text classifiers.

While annotations and lexical terms are directly stored within the repository, the language resources for rule based extraction and classification are only identified by respective URIs. Most importantly all *peer:LanguageResource* but the linguistic annotations should have an associated core Entity linked via the *peer:hasAlias* property to provide integration the recognised text entities.

3 DETAILING THE CORSO ONTOLGOY

To utilise and validate the Coprime components on actual AEC/FM text documents the most general CORSO ontology needs to be detailed with domain-specific and application-specific Core concepts and corresponding Peer representations.

Starting from a documents perspective, case studies of common real-life project documents as well as respective metadata standards and conversation models are conducted to complement the ontology repository and configure text analysis components. Based on these studies comparisons with corresponding engineering data models are planned to finally provide for ontology based information integration.

In this context, the following sections present the results of a preliminary study comparing selected document metadata standards.

3.1 *Metadata standards*

Metadata are used to describe structured as well as unstructured information on different levels of granularity. In the study metadata standards from different domains and application areas have been reviewed. They comprise metadata schemata and formats specifying attributes, data types and a respective syntax as well as metadata nomenclatures specifying controlled vocabularies for the attributes.

3.1.1 *Library metadata standards*

Metadata schemata and nomenclatures are first of all available for *bibliographic cataloguing* (Koch 1997, Umlauf 2006). Today most library metadata is created according to cataloging rules and structure of the Machine-Readable Cataloging format (MARC) based on ISO 2709. For the classification of the documents, content library as well as general knowledge classification systems such as the Dewey Decimal Classification (DDC), die Universal Decimal Classfication (UDC) and die Library of Congress Classification (LCC) are used. Besides these bibliographic standards there are respective cataloguing standards also from e.g. the Federal Geographic Data Committee (FGDC) or the Consortium for Interchange of Museum Information (CIMI) (Baca 2000).

3.1.2 *Metadata for digital resources*

In comparison to these comprehensive metadata standards, the metadata standards for managing electronic resources represent rather simple schemata. Moreover, often there are no nomenclatures associated with the attributes of recommendations such as the IAFA/WHOIS++, the URC, LDIF and WebDAV from the The Internet Engineering Task Force (ITEF 2008). A very comprehensive metadata framework for multimedia resources represents MPEG-7 (ISO/IEC 15938) that comprises numerous schemata, nomenclatures as well as respective developing tools to describe the technical and contextual as well as referential and perceptual features of audio and visual media.

Finally, most influential for the annotation of digital resources have been the specifications of the Dublin Core Metadata Initiative (DCMI). Intentionally the *Dublin Core Metadata Element Set* (DCMES, ISO 15836) has been restricted to a set of fifteen core elements and only a few recommended element-refinements. Both elements and element-refinements are all optional and have no predefined order. Moreover, some established library and internet nomenclatures, called encodings-schemes, are recommended such as the DDC, UDC and the LCC as well as MIME Types (ITEF 2008), the ISO 639 language codes and the ISO 3166 country codes.

3.1.3 *Metadata standards for record, document and content management*

Metadata standards for managing digital records, documents and content have been primarily developed for public administrations and e-learning. Besides common technical and descriptive metadata these specifications often also consider the functions and intended use of the documents.

General recommendations for record management and respective metadata schemata are defined in ISO 23081. A more detailed metadata model is provided e.g. by the Australian Recordkeeping Metadata Standard for Commonwealth Agencies (RKMS 1999) that defines 20 elements (eight mandatory) and 65 sub-elements/terms for the record keeping systems. Finally, the new European Model Requirements for the Management of Electronic Documents and Records 2 (MoReq 2008) specifies an extensive number of metadata attributes and nomenclatures, describing e.g. the documents' actors, life-cycle, content type, relations, usage, technical characteristics.

Metadata standards for e-Learning provide for a detailed annotation of educational documents as well as single content objects such as chapters, graphics or videos. Most prominent standards are the Learning Object Metadata (LOM, IEEE 2002) and the Shareable Content Object Reference Model (SCORM, ADL 2006). Besides comprehensive metadata schemata with general contextual and thematic information these standards also provide attributes and nomenclatures for characterising the usage and didactical goals of each resource.

3.1.4 *Metadata standards for AEC/FM*

In AEC practice document management systems first of all rely on software-specific metadata schemata that are built on technical standards such as WebDAV. Despite several research approaches particularly in the 90's such as DocLink for standardisation of DMS APIs there is no standard available for defining AEC/FM document metadata today (Watson, & Davoodi 2002, Björk 2003).

Metadata for structured AEC/FM documents are defined in EDI-standards for tendering and procurement e.g. from the British Construction Industry Trading Electronically (CITE 2008) or the German Gemeinsamer Ausschuss Elektronik im Bauwesen (GAEB 2002). However, while these standards provide very detailed metadata for their specific application area they often lack several other general contextual and technical attributes.

In addition to the lack of AEC/FM specific metadata schemata, there is a particular need for corresponding nomenclatures. A systematic vocabulary of AEC/FM terms is first of all provided by the construction classification systems such as Uniclass (Uniclass 1997) and OmniClass (OmniClass 2006). They have been widely used to build up company-specific code systems for labeling project documents (Kang et al. 2005).

Despite all these efforts, allocating particular classification tables (or combinations) to certain metadata attributes remains a difficult task. On the one hand there are comprehensive classifications of e.g. organizational roles or forms of information. On the other hand these facets often reflect different perspectives on one subject so that the terms cannot be consolidated and general associations with other tables cannot be established. Moreover, there are vocabularies missing, e.g. for describing document life-cycles, terms are often too general for the application in document and content management, etc.

3.2 *Comparing metadata schemata*

All of the presented metadata standards comprise components that can be adopted for the annotation and management of construction documents. However, to remain manageable the CORSO ontology only considers those metadata attributes that are actually used in practice as well as those that support further text retrieval and integration. It is unlikely, that AEC/FM companies will adopt comprehensive record managing standards, such as MoReq2 that comprises 195 metadata elements, within the next years. Hence a selection of midsize schemata such as the WebDAV, DCMES, RKMS, LOM, DocLink and GAEB have been reviewed.

To better compare metadata standards we can differentiate different categories of metadata attributes. As depicted in figure 2 we first of all distinguish metadata attributes on different content levels:

– *Information elements* represent single or multiple token expressions that can be interpreted without further grammatical rules of the corresponding natural or formal language.
– *Content objects* combine multiple elementary objects into logical units such as sentences, paragraphs, sections as well as graphics in regard to their content type, topic and language format.
– *Documents* combine multiple content objects into documents that are handled as logical units among humans and systems. The content of a document can be encoded within the document as well as within referenced documents (composite document).
– *Corpora* bundle multiple documents for a specific purpose such as its publication or archiving. Most often the documents of a corpora remain independent objects that are combined by separate index document.

Frequently, metadata attributes are differentiated from functional point of view describing technical, contextual and content-related aspects. Baca (2000) for example distinguishes:

– *Administrative metadata* used in managing and administering information resources
– *Descriptive metadata* used to describe or identify information resources
– *Preservation metadata* related to the preservation management of information resources
– *Technical metadata* related to how a system functions or metadata behave
– *Use metadata* related to the level and type of use of information resources.

An alternative classification particularly suited for the perspective of content-based retrieval is presented by Stuckenschmidt & Harmelen (2005). With regard to the relation to the content metadata they classify metadata attributes as follows:

– *Content-independent metadata* is data about information that does not directly relate to the content of the information it describes. It rather describes the context and the environment the information is created and maintained in.
– *Content-dependent metadata* is data about information that is derived from the information. It does not describe the information content, but rather additional properties that directly follow from the content, such as the number of words.
– *Content-based metadata* directly reflects the content of an information source, but it adds information or structure to help processing the original information. Examples of content-based metadata are document vectors and indices.
– *Content-descriptive metadata* finally is data about information that provides an abstract description of the content of an information resource, e.g. in the form of keywords or thematic categories.

Figure 3 depicts a small excerpt of the overall metadata comparison. Overall the metadata standards represent rather straight-forward attribute lists on the document level with considerable overlap. Particularly, technical and partly administrative metadata can be systematically represented in the CORSO ontology.

Most standards support a common set of technical metadata attributes using corresponding nomenclatures for URIs, MIME-Types as well as language and country codes from ISO, W3C and ITEF.

There are also some common metadata elements representing the contributors and users of documents. However, only the DMS-related schemata provide for a role-based specification of the actors as pursued for the CORSO ontology.

Deviations exist among the metadata elements for describing the document life-cycle, the property rights and restrictions of the documents. Only the RKMS defines coherent metadata objects with attributes documenting the document history of revision, preservation and usage.

From the perspective of content-based retrieval the standards particularly lack metadata elements for

	DCMES	RKMS	LOM
Actor	Creator	Agent	Contribute
Actor	Publisher	cf. Agent	cf. Contribute
Actor	Contributor	cf. Agent	cf. Contribute
Actor	RightsHolder	cf. Agent	cf. Contribute
Actor		cf. Agent	cf. Contribute
Life Cycle & Rights	Date	Date	Date
Life Cycle & Rights			Version
Life Cycle & Rights			Status
Life Cycle & Rights			
Life Cycle & Rights			
Life Cycle & Rights		Management	
Life Cycle & Rights			
Life Cycle & Rights		Use History	
Life Cycle & Rights		Preservation	
Life Cycle & Rights	Provenance		
Life Cycle & Rights	AccrualMethod		
Life Cycle & Rights	AccrualPeriodicity		
Life Cycle & Rights	AccrualPolicy		
Life Cycle & Rights	Rights	Rights	Copyright & Restrict.
Life Cycle & Rights			
Life Cycle & Rights			Description
Life Cycle & Rights		Disposal	
Life Cycle & Rights		Mandate	
Manifestation	Identifier	Record Identifier	Identifier
Manifestation	Title	Title	Title
Manifestation	Source	Location	Location
Manifestation	Format	Format	Format
Manifestation			Size
Manifestation			Installation Remarks
Manifestation			Other Platform
Content Use			Cost
Content Use	Audience		Intended End User
Content Use			Typical Age
Content Use			Description
Content Use			Context
Content Use			Language
Content Use			Difficulty
Content Use			Semantic
Content Use	InstructionalMetho		Interactivity Type
Content Use			Interactivity Level
Content Use			Duration
Content Use			Typical
Content Description	Language	Language	Language
Content Description	Type	Type	Learning Resource
Content Description		Funktion	
Content Description	Description	Description	Description
Content Description	Subject	Subject	Keyword
Content Description	Coverage	Coverage	Coverage
Content Description			Taxon Path
Relation			Structure
Relation		Aggregation Level	Aggregation Level
Relation	Relation	Relation	Resource (Relation)

Figure 3. Exerpt from the metadata comparison.

the description of the documents' content and their indented use. There is considerable overlap of the metadata attributes for describing the documents' content. However, most of these attributes only provide placeholders for general keywords or classification codes, but the existing library, business and construction specific classifications are not sufficient to classify the documents for common communication contexts. The intended use of the documents is only recognised within the e-learning standards that provide nomenclatures e.g. for describing technical and educational requirements of a course component, its teaching/learning modus as well as related components.

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Value-driven processes and value-chain management

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

3D Building model-based life-cycle management of reinforced concrete bridges

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ABSTRACT: Since large parts of western countries' infrastructure have been erected in the early 1960's, many infrastructure buildings such as concrete bridges are now entering a critical age, where the need for continuous inspection and reconditioning is becoming apparent. Facing these challenges, many national highway authorities have developed computer systems that allow for the management of data collected during bridge inspections. Based on this data the current condition of the inspected bridge is manually assessed and, if necessary, revivification measurements are planned. The life-cycle management tool presented in this paper goes one step further: It allows a 3D model-based, component-wise collection of detailed material and inspection data and a mostly automated computation of the bridge's future state by using probabilistic deterioration models for all individual components and hierarchical aggregation of the components' conditions. The basis of the component-wise input and processing of all relevant data forms a hierarchical 3D building model, which is described in detail in the paper. The particularity of our approach is that the building model can easily be adapted to specific building types or the special demands of regulatory authorities by means of an explicitly available meta-model.

1 INTRODUCTION

1.1 *Motivation*

Most of the public and private bridge operators in the western countries are faced more and more with the problem of maintaining a stock of aging bridges with just limited funds at their disposal (Schiessl and Mayer 2006). This has given rise to the development of Building Management Systems (BMS) and Life-cycle Management Systems (LMS). These systems offer computer-aided support for planning and realization of bridge inspections and repair works.

The most import feature of an LMS is that information from inspections is stored and can be reviewed at any time. Furthermore this data is used to compute the building's current and future condition, described within a system of condition grades. Two major drawbacks of many existing LMS are the lack of adequate deterioration models and the use of merely visual inspections in order to detect possible structural damages (e.g. cracking, staining, spalling). In most cases the optimal point in time for (preventive) repair measures of concrete building elements is already exceeded once deteriorations are visible at the concrete surface.

Predictive life-cycle management systems (PLMS) follow a novel approach to overcome this major drawback of conventional LMS. To detect deteriorations earlier additional non-destructive and visual inspection techniques are used in combination with fully-probabilistic deterioration models to predict the condition development of building elements. The prognosis is constantly updated, thus yielding a more precise prognosis of the future condition development. Such a PLMS can thus be used to optimize the operation of bridges over their entire service life (Schiessl & Mayer 2006). Furthermore, the system supports the institutions responsible for bridge maintenance in the long-term planning of inspections and repair measures at both bridge-level and network-level. Another advantage is that budgeting for reconditioning measures can be planned more precisely.

In a current research project we are developing a software-tool for the predictive life-cycle management of reinforced concrete bridges. A 3D building information model (BIM) forms the center of this system. All relevant data like measurement results, photos, or condition prognoses are stored within the BIM. This way, the owner of a stock of bridges can easily obtain an overview of the condition of individual structures or the complete bridge stock. The hierarchic subdivision of structures into building elements, sub-elements and hotspots chosen for the BIM allows for a detailed allocation of information.

1.2 *Related work*

Several life-cycle management systems for bridges are already in operation. In Germany "SIB-Bauwerke" has been developed by the Bundesanstalt für Straßenwesen and is now in use on national and federal state level (Haardt 2002). The following list shows some systems from other countries (the list does not lay claim on completeness):

- Bridgelife in Finland (Vesikari 2006),
- DANBRO in Denmark (Henriksen 1999),
- Eirspan in Ireland (Duffy 2004),
- Kuba-MS in Switzerland (Haller & Basurco 2006),
- Pontis (Robert et al. 2003) and Bridgit (Hawk 1999) in the USA
- Ontario Bridge Management System in Canada (Thompson 1999)

At present "mobile model-based bridge lifecycle management systems" are being developed in Canada (Hammad et al. 2006).

The above listed systems can be characterized by the following properties:

- Except for the "mobile model-based bridge life-cycle management systems" (Hammad et al. 2006) the geometry of the bridge is not stored. Thus, photos or measurement results can only be allocated to building elements as text information.
- Adding a bridge to such a system, the bridge is structured horizontally into "parts" and vertically into levels. The number of levels differs from system to system. The smallest "part" in all these systems is a building element. A further subdivision is not used in any of these systems.
- Computing the condition prognosis of building elements or the whole bridge deterministic models (e.g. Haardt 2002, Henriksen 1999) or Markovian Chain-systems (e.g. Vesikari 2006) are used, respectively. Fully-probabilistic deterioration models are not used in any of these systems. The condition of a building is assessed manually, solely on the basis of visual inspections. Other non-destructive inspection methods are rarely used.

1.3 *Deterioration mechanisms, measurement methods, repair measures*

Reinforced and pre-stressed concrete bridges can be subject to different deterioration mechanisms such as corrosion of the steel reinforcement, freeze- and freeze-thaw-attack or alkali-aggregate-reaction.

Among them, the corrosion of the steel reinforcement due to chlorides from de-icing salt or carbonation of the cover concrete are the most important mechanisms. Chloride-induced corrosion is initiated once the concentration of chlorides ingressing from the concrete surface to the steel rebar exceeds a critical chloride concentration and shifts the rebar surface from its originally passive state into a state of active corrosion.

As both chloride ingress and carbonation of the concrete cover as well as the early stages of rebar corrosion cannot be detected visually, different non-destructive inspection methods have been developed in order to assess the present state of the structure (e.g. potential mapping, concrete cover mapping, determination of carbonation depth or determination of chloride profiles).

Aside from these possibilities to assess the condition state on site, recent achievements in the field of deterioration modeling nowadays allow for a reliable prognosis of both chloride ingress and carbonation and the subsequent corrosion of the reinforcement by means of fully-probabilistic deterioration models (Gehlen 2000). Inspection results can be used to continuously update the original prognosis, thus yielding an improved knowledge of the future condition development as the base for possible rehabilitation measures. Depending on the owner's maintenance strategy, these measures can range from preventive coating of concrete surfaces to a replacement of chloride-contaminated concrete or a cathodic corrosion protection of actively corroding structures.

2 THE PREDICTIVE LIFE-CYCLE MANAGEMENT SYSTEM

2.1 *Architecture*

The architecture of the life-cycle management system we are developing is shown in Figure 1. The system consists of five modules, each of them representing a particular stage in the life-cycle management workflow, and a central database where all required data is stored. The individual modules are:

Acquisition module. In a first step, the bridge manager enters all construction-related information, including the 3D geometry of the bridge, the material parameters and the known environmental loadings. Additionally, the bridge model is semantically structured by assigning classes of building elements to individual 3D solids, grouping similar elements, and arranging them in a level-of-detail like hierarchy. To this end, the responsible engineer uses the acquisition module which offers not only means to import 3D geometry from standard CAD formats, but also provides an intuitive way for structuring the building and assigning life-cycle relevant parameters to

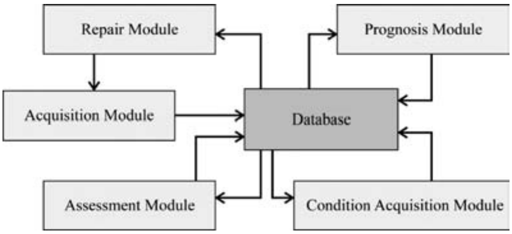

Figure 1. The modules of the predictive life-cycle management system (Schiessl and Mayer 2006).

individual components or even individual faces of the component's surface.

Condition Acquisition module. The condition acquisition module helps in capturing the current condition of the respective building. In the first step this module is used to determine which kind of inspection methods are required. Depending on the building's or building element's condition, adequate inspection measurements are suggested. The actual condition data can be obtained from discontinuous or continuous, laminar or single-pointed measurements and from sensors. In case of an inspection, the module assists in capturing newly found cracks by providing means to "draw" them or to stick digital photos on the respective surface in the 3D model, for example.

Results from measurements carried out during an inspection (such as concrete cover mapping, carbonation depth or depassivation depth, chloride profiles) are also stored in the PLMS by means of the condition acquisition module. The module furthermore is able to collect and filter data from databases that are fed from sensors such as multi-ring electrodes for the determination of moisture profiles or anode-ladders for the time-dependent ingress of the depassivation front. Again all measurement and sensor information is localized within the 3D building model.

Prognosis module. Using the prognosis module, future condition changes are calculated for every building element. For the update of the original prognosis, results from non-destructive inspection methods for each building element are used. Therefore deterioration models must be defined and stored in the database.

Assessment module. The assessment module determines the optimum time for any kind of repair measures on the basis of the actually prognosticated condition changes. One aspect for repair measures is to eliminate possible damages at an early stage, thus the construction will last for a longer time and money can be saved because such a *preventive* repair measure is in many cases cheaper than the repair of a damaged building element.

Repair module. Whenever repair measures are taken they are recorded in the PLMS using the repair module. Also, the building's component condition after these repair measures is stored. This information is used by the prognosis module to compute a Bayesian update for all condition prognoses.

After a building's completion and taking over, the PLMS will be used for the first time to acquire all relevant information. In this step, the planning data is updated with the real data from the building, which were obtained by using measurement methods. A typical example is the extent of the concrete cover – in many cases it differs from the value instructed by the construction engineer due to an imprecise erection process. This first update of the building's condition prognosis is called a *Birth Certificate* (Mayer et al. 2008).

3 THE HIERARCHICAL BUILDING INFORMATION MODEL

3.1 *3D building model*

Existing life-cycle management systems only provide means for textual input of inspection data. Thus the inspection planner has the challenging and error-prone process to mentally assign material parameters, damages and measured values to real locations and individual building components.

We therefore propagate the use of a 3D building model as the center of all data acquisition and data retention activities. By means of this model, all information about material properties, environmental loadings, deteriorations, inspections, repair measures, and condition changes are stored with reference to geometric objects. Furthermore all results of non-destructive inspection techniques or photos taken during inspections can be attached to the geometric representation of the corresponding building component. Using a 3D model, all relevant information is easily allocated and a very good overview is guaranteed.

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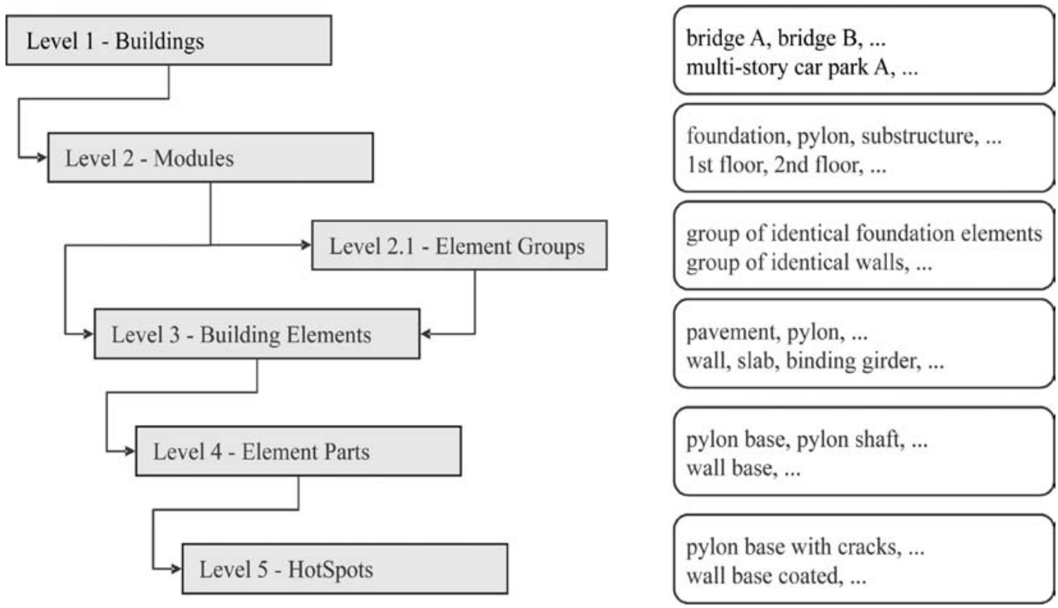

Figure 2. The hierarchical Building Information Model in use for the PLMS consists of five main levels and an additional grouping level. All child elements are physically contained in the parent element, such that their geometry forms part of its parent's geometry. The prognosis is based on this hierarchy such that the condition grades of the lower level define that of a higher level (Schiessl & Mayer 2006).

3.2 *Multi-level semantical model*

A pure geometric model would not fulfill the demands on a PLMS - the type of each building component and its role in the structural system are decisive for its influence on the condition of the overall building. The system therefore forces the user to assign classes to individual geometric elements, following a kind of reverse product modeling approach. We call it "reverse" since in the standard product modeling process, the semantics of an object are first defined, and based on that, a geometric representation is assigned (Eastman 1999).

Additionally we realize a multi-level, hierarchical model here. The proposed hierarchy consists of five different levels, each entity on one level has none or more child elements on the next level. All child elements are physically contained in the parent element, such that their geometry forms part of its parent's geometry. Except for the last level, all child elements together form the parent element - a typical aggregation relationship (see Figure 2).

The **first level** represents entire *buildings*. Since the PLMS is designed to manage all buildings of a respective state authority or private owner, we can have multiple entities on this level, such as *bridge A*, *bridge B* etc.

The **second level** comprises *modules*. Modules are groups of building components with identical functionality. For example, reinforced concrete bridges will typically consist of *foundation*, *bridgehead*, *pylon* and *superstructure* modules.

The **third level** consists of individual building elements such as *pavement*, *pylon*, *wall*, *slab*, *girder* etc. On an intermediate level, called level 2.1, all building elements with exactly the same geometry and identical environmental loads are grouped together. This feature was integrated to avoid the multiple inputs of the same data for a number of identical objects. Note that individual building elements can be removed from a group whenever parameters occur which are specific for that element.

The **fourth level** represents individual parts of these elements. Such *sub-elements* like *pylon base*, *pylon shaft* or *wall base* are required to capture specific environmental stresses that occur only at parts of building components. For example, wall bases are especially exposed to splash water which may contain high concentrations of chlorides from de-icing salts and thus cause faster chloride ingress and an earlier corrosion of the steel rebars.

On the **fifth level** *hotspots* are managed. Hotspots represent sectors having a low material resistance and or extraordinarily high environmental loadings which are critical for the condition of the whole construction. Such hotspots can be set by the engineer or bridge-owner in the initial data acquisition process or added as soon as local changes of environmental loadings or extraordinary deteriorations, such as cracks, are detected. A typical example for a hotspot set by the engineer is the anchor point of pre-stressing tendons.

The vertical structuring of a given 3D bridge model and its subdivision into sub-elements and hotspots is performed manually but with strong support by the 3D software interface. Though the process can be seen as rather tedious, it is absolutely necessary in order to make optimum use of the fully-probabilistic deterioration models mentioned above. Only by means of hotspot entities for example, is it possible to capture local deteriorations – an unavoidable pre-requisite for a precise prognosis of the whole structure's condition. Note that data about material resistance, environmental loads and geometric details is allocated only to elements of levels three to five.

Determining the condition of a structure is realized by a bottom-up aggregation of the condition over all levels. With the described levels of detail approach, the owner of a bridge can easily acquire detailed information or assess a construction's condition from the hotspot level to the entire building. This aggregation is achieved by employing multi-attribute-decision-algorithms (MADA) that allow for a different weighting of the criteria important to the owner (e.g. financial/environmental aspects, health, safety), see (Lair et al. 2003) and (Norris and Marshall 1995). To make sure that no important information is lost in this aggregation process, additional limit states are defined for every single element, and the excess of these limit states calls for immediate remedial actions independent of the aggregated state of the whole structure.

3.3 *Making the semantic model adaptable*

Since the developed life cycle management system should not be restricted to the maintenance of bridges, but instead be applicable for a wide variety of building types, we integrated functionality that can dynamically adapt to the available semantic data structures dynamically. This has been realized by means of an explicitly available meta-model.

Figure 3 shows this model; on the left hand side the meta-classes CLASS, ATTRIBUTE and ASSOCIATION are depicted.

The instances of theses meta-classes can be used to model the classes of a specific domain model. For the bridge domain model, for example, we would model a class named *Bridge* having an attribute *owner* of type STRING, an attribute *erection* of type DATE etc. The available simple data types are provided by the enumeration TYPE which consists of BOOLEAN, INTEGER, DOUBLE, STRING, DATE and TIME.

However, we often need to model more complex attributes. For example, we might want to store not only the name of the owner as a simple string, but

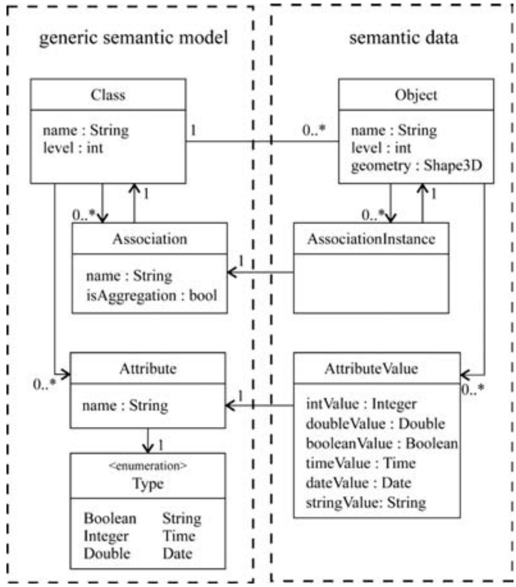

Figure 3. The meta-model used to provide an adaptable Building Information Model. Instances of the meta-classes on the left-hand side are used to model the classes of a domain-specific model and their relationships. Instances of the generic classes on the right-hand carry data of instances of this model.

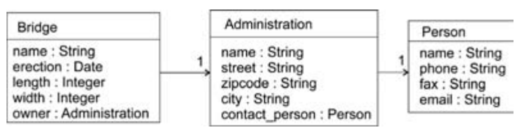

Figure 4. Sample model: bridge – owner – person.

instead use a complex *Owner* class comprising the attributes *name, address, responsibility* etc. To realize this, the meta-model offers the ASSOCIATION facility: each CLASS object can have an arbitrary number of associations. Each ASSOCIATION object itself will point on exactly one other CLASS object. In our example, the latter would be the *Owner* class with the aforementioned attributes. Since the associated class can have associations itself, an arbitrarily complex data model can be generated.

An instance of the meta-model defines the Building Information Model used by the system. Figure 4 shows an instance of the meta-model representing the sample model *Bridge-Owner-Person* and Figure 5 shows the corresponding object diagram.

In our concept, only specially trained personnel (administrators) should have access to the data modeling facilities, since changes in the data structures have a crucial impact on the functions of the whole system. The normal users such as bridge managers, inspectors

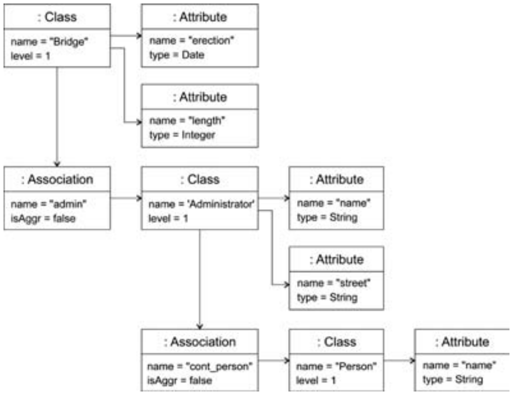

Figure 5. UML object diagram: The domain model of Figure 4 is modeled using instances of the meta-classes from Figure 3, left-hand side.

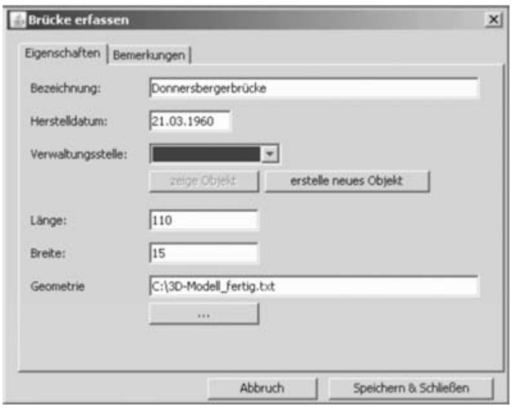

Figure 6. Automatically generated dialog box.

or regulation authorities work with input masks that are directly generated from the data model, but are not able to change it.

On the right hand side of Figure 3 the meta-classes are shown that are capable to hold instance data, i.e. the data of one particular building. They are generic in the sense that they work for any domain model. However, their structure is controlled by the connection to meta-classes on the left hand side. Since all input masks are generated from the domain model defined through the meta-model (see for example Figure 6), the inputed data automatically conforms to the desired data structure. But even without the user front-end, each data entity stays semantically structured: as can be seen in Figure 3, an AttributeValue, for example, "knows" to which Attribute it belongs.

The concept of a BIM that is on the one hand centered on geometry and on the other hand adaptable with respect to the semantic data structure by means of an explicitly available meta-model has already been approved in a number of research projects, e.g. in the context of architectural and structural modeling in early design phases (Steinmann 1997, Kowalczyk 1997), in modeling existing buildings for revivification measures (Hauschild et al. 2003a), and for the realization of a Collaborative Computational Steering system (Borrmann et al. 2006).

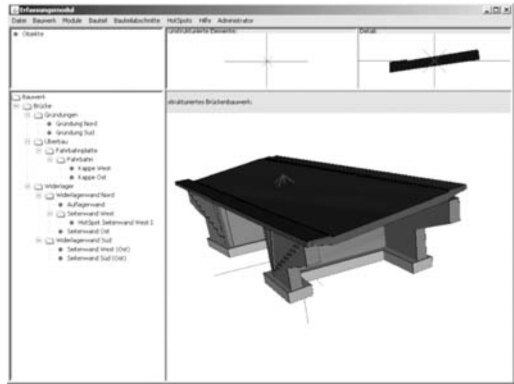

Figure 7. Graphical User Interface of the PLM system.

4 IMPLEMENTATION

4.1 *General information*

The software tool presented in this paper is implemented by coupling a Java application (Sun Microsystems 2006a) with a relational database. All construction information, including geometric data, is stored in this database. A relational MySQL database (MySQL 2007) was chosen as the database management system (DBMS). The advantages of this DBMS are fast access to data, the possibility of storing large amounts of data, and no license fees. The three-dimensional representation of the construction's geometry is achieved with the Java 3D library (Sun Microsystems 2006b).

The advantage of the programming language Java is that applications written in this language can easily be used on different operating systems like Microsoft Windows or Linux. This aspect is very important because potential users of this application (such as administrations, construction firms with PPP-projects) may use different operating systems.

A screenshot of the software tool is shown in Figure 7.

4.2 *Implementation and use of the meta-model*

Realizing the aforementioned adaptable semantic model implies special requirements for the database and the graphical user interface (GUI). According to

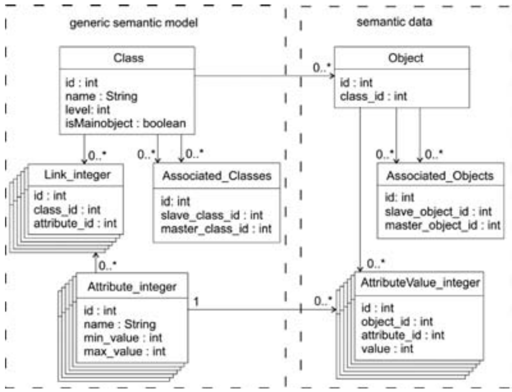

Figure 8. Database structure for the meta-model. Layered boxes describe similar relations used for other attribute types.

the description of the meta-model shown in Figure 3 the database structure consists on the one hand of relations used for the generic semantic model and on the other hand of relations containing the semantic data. In the database, a relation is needed for every attribute type. Since every class can have an arbitrary number of attributes of each type, additional link relations are used to model these m:n-relations, see Figure 8.

In the first step the administrator or some other authorized user creates classes that form the semantic model. These classes are stored in the database. In order to generate the input masks for using the software tool, the following information for each attribute is required: sequence of attributes, limit values for attributes of type INTEGER or DOUBLE, and the number of characters for attributes of type STRING. Determining the sequence of the attributes is important, because this way it is possible to topically arrange attributes of different types in the later input masks. The limit values are needed to identify erroneous user inputs such as negative dimensions.

All input masks will be automatically generated during usage of the software tool, see Figure 6 for example. To this end, the required class from the generic semantic model is loaded from the database. The attributes are placed in the given predefined sequence by the administrator. The system provides assistance for every input. This is done using tooltip texts and a support system. In addition, the user is informed whenever incorrect information has been entered or information is missing when closing a dialog box. Further information is given if complex attributes are used and there is still some input missing when closing a dialog. As soon as all entries are correct and accepted by the user, a new object is generated and stored in the database.

The following input components are automatically created by the software tool: If the user creates a new building (level 1) he has to choose a file that provides the geometry of the building as a B-Rep model. All geometry data is stored in the database, as explained in the next section. In the next step, the user has to structure the building model according to the vertical levels and the semantic data model (see Section 3.2). To realize this, he creates instances of the available classes and assigns a geometric object to everyone. The user is supported during this process by visualizing classified and non-classified building elements in different 3D views. When creating a new element part, the user may choose whether this object has a geometric representation or not. A building element does not have its own geometric representation if it is completely subdivided into sub-elements. However, for all new sub-elements and hotspots a geometric representation must be chosen. Every object with a geometric representation needs further input of material properties.

All construction information stored in the database can be visualized and edited anytime by the GUI. One special aspect of this GUI is that an intuitive and user-friendly interaction is possible everywhere – at an office desk or during a bridge inspection.

4.3 *Geometry*

Visualizing the geometric representation of the building is realized by means of the Java3D library (Sun Microsystems 2006b), see Figure 7. Using this library the user can interactively translate, rotate, or scale the model. Furthermore a single object can be marked by clicking and the properties of this element will be shown.

The software prototype uses a geometry structure very similar to the geometry kernel ACIS (Spatial 2006), see Figure 9. The advantages of this structure are: All building elements are represented by faces. Therefore nearly all information in this tool is stored geometry-based, it is very important to have direct access to all faces. Furthermore it is possible to describe building elements with holes, like box-section slabs. The export of the geometric data from a CAD application, like AutoCAD, is done by creating a temporary file containing this information. This file is read by the acquisition module into the software tool and all parts are visualized as objects. In the next step these objects are used to generate the building model's structure using the level of details described in Section 3.2 and shown in Figure 2.

The building's complete geometry representation is stored in the database. The representation of single building elements and the associated objects are linked by the attribute GEOMETRY as shown in Figure 3.

4.4 *Implementation of the PLMS*

Acquisition module. Using the acquisition module shown in Figure 7, all information about a building

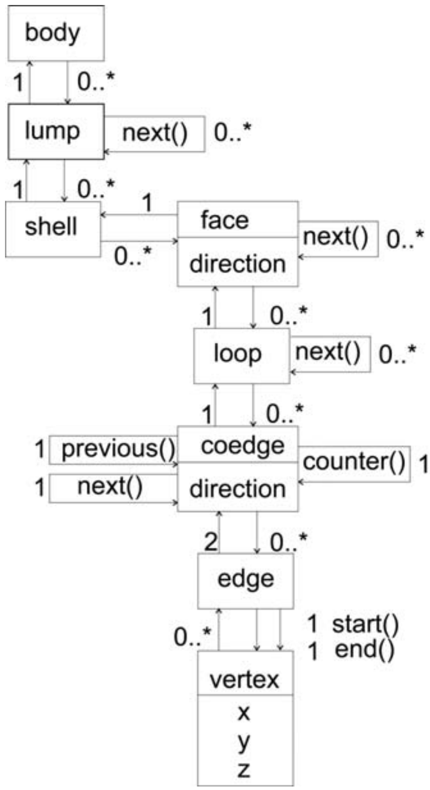

Figure 9. Geometry schema in use by the PLMS.

is entered. Beginning with level 1 (see Figure 2) the building structure in the software tool is generated step by step. For every new object the appropriate input mask is generated using the information given by the assigned class. This meta-information is read from the database. The complete acquisition is done – as everything else – using the GUI. During the acquisition process, general and geometry based data, such as material, concrete cover, environmental loads, is entered and stored in the database. An example for the input mask for general information is shown in Figure 6, for geometry based information in Figure 10.

For speeding up data acquisition, extendable lists for special inputs have been integrated into the software tool. Those lists are available for the following properties: materials, defined material parameters, environmental loads, repair measures, deterioration models, and types of building elements. Using these lists to create input masks for the software tool we can achieve a highly effective workflow. The lists are stored in the database and can be updated by the user or the administrator, respectively. For example, it is possible to define an arbitrary number of environmental loads, each of which is defined by a number of

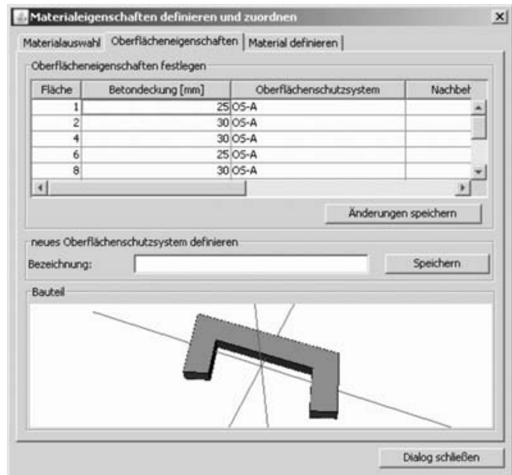

Figure 10. Assigning information to faces.

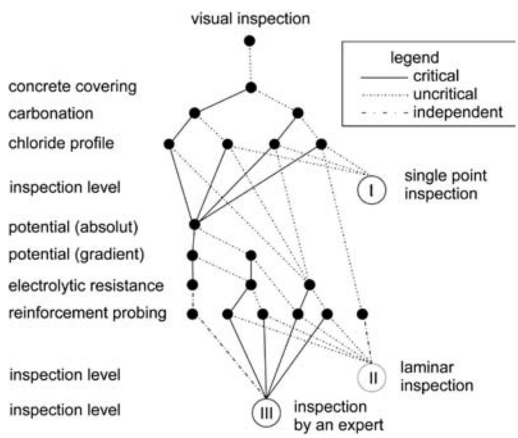

Figure 11. Decision tree for choosing the required inspection level.

parameters. This functionality for defining environmental loads renders the systems extremely flexible, which is necessary to ensure its usability over the long life-span of a concrete building.

Condition Acquisition module. Using this module, the results from all kinds of measurements are assigned to the appropriate element's face. Which kind of measurements should be used will also be decided within this module. The number of required measurement methods depends on the part's condition and its deterioration mechanism. A decision tree is used for choosing the right methods. In the framework of this research project, three inspection stages (I to III) are being developed. In Figure 11 the decision tree in the case of reinforcement corrosion is shown. The three stages are defined as following: single pointed measures (stage I), laminar measures (stage II), and measures carried out by an expert (stage III).

All inspection results are also stored in the database. To this end, there are a lot of different discontinuous measurement methods and sensors for continuous monitoring available; consequently, another meta-model for measurement methods and measurements will be introduced. This one will be designed in a similar manner to the one already presented in Figure 3. The main difference will be that the generic semantic model is used to describe measurement methods and sensors, and on the right hand the semantic data is used for the applied measures including date and time information.

Prognosis module. For computing the prognoses the prognosis module needs all information assigned to the building elements. In the first step the bridge manager must choose the appropriate deterioration mechanism for every part, if necessary. It is not possible to do this automatically because lots of expert knowledge is needed to select the right deterioration mechanism. Predicting the progressive decline (of a structure's condition) will be probabilistically calculated using the software package STRUREL (RCP 2007). We intend to establish a corresponding interface between the software package STRUREL and the PLMS to enable the required data exchange.

Assessment and repair module. We have not yet begun implementing these two modules.

5 SUMMARY

In an ongoing research project, we are developing a software system for the predictive life-cycle management of reinforced concrete bridges. A key feature of the PLMS is a 3D building information model which forms the basis of all data acquisition and evaluation functionality. This model serves to store all information on building elements together with their relation to the geometry. The model provides multiple levels of detail and means to associate semantic classes with geometric objects. Since the PLMS is designed for different kinds of building types, an explicitly available meta-model has been integrated which is used to generate a specific BIM.

What first distinguishes this software tool from other existing building management systems is the fact that a construction is subdivided into up to five levels (of detail). In an initial step, structures are first subdivided into modules and then into building elements. Component parts are subdivided into sub-elements and hotspots. The advantage of this approach is that results of inspections or photos can be directly allotted to the corresponding geometries. This subdivision is necessary in order to make use of fully probabilistic deterioration models.

For predicting future changes in the condition of a structure, these fully probabilistic deterioration models are used in conjunction with non-destructive inspection methods. The construction's condition is computed by aggregating the conditions over all five levels. It is accordingly possible to detect damage at a very early stage and plan repair measures to eliminate such damage. This consequently means a reduction in the financial outlay for the maintenance of the structure.

The predictive life-cycle management system is implemented by coupling a Java application with a relational MySQL database. The GUI provides a simple, innovative way to store new constructions in the database. All information can be entered and modified using this interface. There are special requirements for the database and the GUI by using the meta-model, which are extensively discussed in this paper.

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Decision support in Petri nets via genetic algorithms

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ABSTRACT: To the best advantage, building processes can be modelled with Petri nets. As an extension of building processes, material flow can be simulated with adapted Petri nets. In addition, the nets need a notion of time and coloured tokens and are therefore called discrete deterministic coloured Petri nets. For a user support in decision making in such complex nets, the optimal material flow has to be found. According to the size of the specific Petri net and the duration of the simulation, the amount of possible material flows can be enormous. In order to reduce the number of necessary flow simulations and to guarantee a decision support answer in an acceptable amount of time, Petri nets are coupled with genetic algorithms. In this contribution we discuss potentials, challenges and solutions of genetic algorithms applied to Petri net flow simulations. First results approve in principle the practicability and efficiency of this approach.

1 INTRODUCTION

For the last couple of years, process models have been our main objective within two research projects supported by the German Research Foundation (DFG). Within the first project "Relation Based Process Modelling of Co-operative Building Planning" we defined a consistent mathematical process model for hierarchical planning processes and developed a prototype implementation of a tool to model these processes. In addition to the mere modelling of the planning, the tool also allows a user to simulate the work flow in a Petri net.

In continuation of this research work within the transfer project "Verification of a Tool for Co-operative Planning in Practice" the simulation of material flow proved to be a remarkable benefit as well. Still, the succession of the flow is user controlled. He has to choose from alternatives. Since the material flow in a large net offers many possibilities, the user needs assistance in his decision making, a decision support system (DSS). In this paper we will present an approach of decision support calculations based on a special form of artificial intelligence: genetic algorithms.

2 DISCRETE DETERMINISTIC COLOURED PETRI NET (DDCPN)

2.1 *Petri nets*

Processes in civil engineering can be simulated with Petri nets. The basic Petri net is a Place-Transition-Petri net. It is an amplification of a directed bipartite graph. The two types of nodes are called places and transitions. They are connected by directed arcs. Arcs can run from a transition to a place or the other way around, but not between two nodes of the same type. Places can hold tokens to indicate the state of the net, the state of the process. This distribution of tokens is called a marking.

Two features are possible, but not necessary for a basic Petri net: Places can have capacities, and arcs can have weights. The capacity of a place limits the number of tokens the place can hold. The weight of an arc describes the number of tokens the arc is able to transport at the same time.

Assuming the Petri net *PN* includes weights for arcs and capacities for places, it can be described with formula 1.

$$PN = (P, T; F; C, W, M) \tag{1}$$

P is a set of places. T is a set of transitions. F is a set of arcs called flow relation: $F \subseteq (P \times T) \cup (T \times P)$. C: $P \to N^{+} \cup \{\infty\}$ are the capacities of the places, and W: $F \to N^{+}$ the arc weights. $M : P \to \mathrm{N}$ is the marking. Each place $p \in P$ holds $n \in N$ tokens.

When a transition is executed (fired), it deletes tokens from its input places and creates new ones at its output places. Input places are places with an arc directed to the transition and denoted $\bullet t$. From the transition arcs point to the output places $t\bullet$. In consequence, input and output places have to fulfil the following conditions before the transition can be fired:

$$\begin{aligned} &\forall p \in \bullet t : M(p) \geq W(p,t) \wedge \\ &\forall p \in t\bullet : C(p) \geq M(p) + W(t,p) \end{aligned} \tag{2}$$

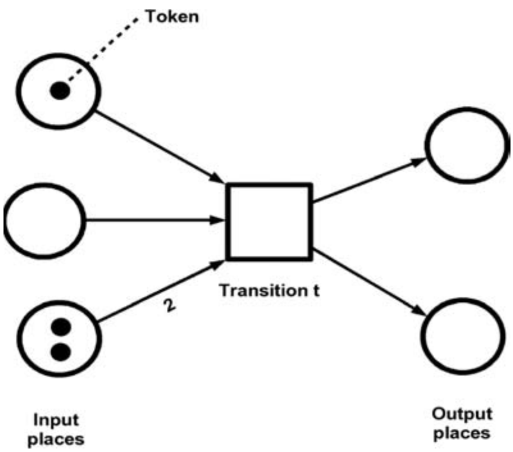

Figure 1. Section of an anonymous Petri net.

Each input place must hold enough tokens according to the weight of the related arc. At each output place the difference between its total capacity and the already held tokens must be greater than or equal to the number of tokens transported by the related arc. Then the transition could be fired. In this state the transition is called active or enabled.

Figure 1 shows a section of a Petri net consisting of one transition with its input and output places. One arc has the capacity two. Transition t is not active in the shown state of the net, because one input place does not hold the necessary token.

The procedure of deletion and creation of tokens is possible, because the tokens do not contain any information. Only their mere existence is important to the state of the Petri net. Thus, the tokens and in consequence also the net are called anonymous.

This type of Petri net is sufficient to simulate the workflow of building processes. It models the logical sequence of the process without a notion of time. In order to simulate processes more precisely, Petri nets must be enhanced with new elements.

2.2 *Colour*

A Petri net to simulate material flow needs more capabilities than an anonymous net. Petri net formalisms that extend the basic Petri net are called high-level Petri nets. These nets are more powerful, but, on the other hand, it is harder to analyse and calculate them.

In our case of material flow, an additional two important features are required: the first is the "colour".

Tokens cannot be anonymous any longer. A token represents a unit of material. Therefore, different types of tokens are defined to represent the different materials. Information must be stored in and retrieved out of the tokens. They can be distinguished from each other.

The type of a token is also important to a transition. It can influence the behaviour of a transition. In consequence, a transition cannot delete and create tokens anymore, it must transport them.

Since different types of tokens are often graphically displayed in different colours, a net with distinguishable tokens is called a coloured Petri net.

2.3 *Time*

The second feature, which is essential for the net in order to simulate material flow, is the notion of time. To analyse and evaluate the performance of a material flow, the introduction of durations for transport processes is inevitable.

In a Petri net, all actions are carried out in discrete (time) steps. There are several options where time could be consumed in the net, e.g. by transitions, places or arcs. Since the transitions represent activities, and the execution of activities requires time, we chose the transitions as location for the consumption of time, the so called delay.

When a transition is fired, it is marked as being executed for the determined duration. Furthermore, a transition can have a capacity to limit the number of concurrent firings. Van der Aalst distinguishes "three types of capacity related semantics: *single server semantics*, *multiple server semantics*, and *infinite server semantics*." For single server semantics, the capacity of a transition is one. For multiple server semantics, it is a preassigned integer value, and for infinite server semantics, there are no capacity restrictions.

Special attention has to be paid to the capacities of places. With time-consuming transitions, they can cause inconsistencies in the state of the net. Consider a place with a capacity of one, which is the output place of two transitions. The first transition is executed. Meanwhile, the second transition checks its environment. It will find the output place empty and might therefore be executed. When the first transition terminates its activity, it creates a token in the output place. At the end of the second transition, it cannot deliver the token to the output place, because the capacity of the place is exhausted. To resolve this problem, tokens are transported immediately when a transition is fired. They are marked as inactive, but reserve the space in the output place for the duration of the transition.

For the type of the delay, there are 3 options: deterministic, non-deterministic with a value-range or stochastic with a probability distribution. Since our net is user-interactive in discrete time steps, we chose deterministic delays. The duration can be different for every transition, but it is fixed. These colour and time feature enhanced Petri nets are called discrete deterministic coloured Petri nets (DDCPN).

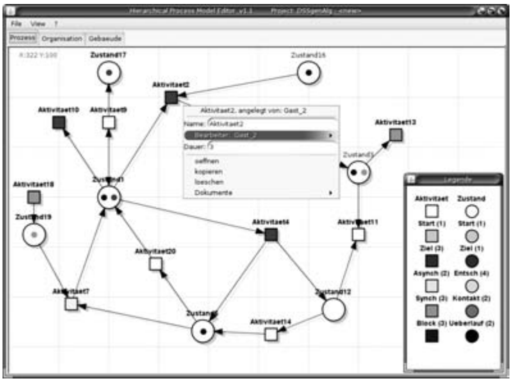

Figure 2. The simulation tool.

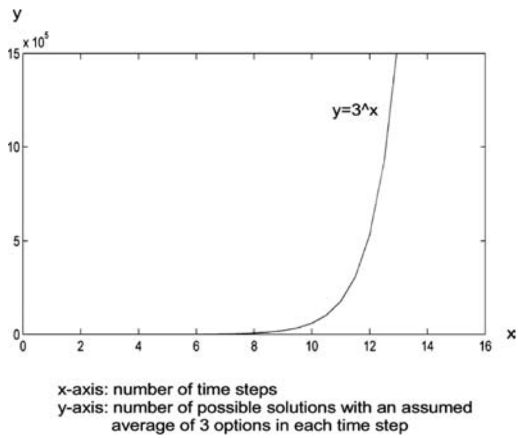

Figure 3. Number of possible solutions over the time.

3 DECISION SUPPORT

The above described discrete deterministic coloured Petri net is able to simulate material flow. Time progresses in discrete steps. Within these steps, the user has the duty to control the material flow by deciding which transitions are fired with which amount of tokens (figure 2).

Along with the surveyed period of time, the simulation of a large net can produce an unmanageable amount of possible material flows. Thus, a decision support system (DSS) is valuable to assist the user.

The task of the DSS is to provide the user with the "best" options. We decided to display the three best choices, the next steps of the three best material flows, if available.

In order to determine the best options, the state of the net must be evaluated at a certain point in time. Therefore, we have to specify two things: the criteria for the evaluation and the point in time. The criteria will be discussed in chapter 4.2.

The point in time of the evaluation must be in the future. The extreme on the one side is a so called greedy algorithm. Greedy algorithms solve optimisation problems iteratively. At every point in time, they select the best alternative for that specific moment, causing the name "greedy". Calculation is only from one time step to the next. Thus, greedy algorithms find local optima, not necessarily global ones, and are therefore not appropriate for material flow, because they are too short-sighted.

The extreme on the other end would be a simulation until the end of the project. But a long term simulation is difficult as well. There can be numerous possible decisions for the material flow in every time step. The total number of possible combinations therefore rises exponentially over the time and quickly reaches a magnitude that cannot be controlled anymore. Assuming an average number of three possible flows in each time step, 13 time steps produce more than 1.5 million combinations (figure 3). 19 time steps exceed a billion.

Thus, the point of the evaluation is essential to the number of possible combinations, and a reasonable value has to be found. We chose minutes as the discrete unit for the time steps, which does not imply that a time step occurs every minute. Time steps are only needed when the net changes. Their length is variable. One day is the maximum period of time for the simulation. All transitions must have terminated before the end of the day.

To find the best solutions out of all these possibilities is a combinatorial optimisation problem. There are several ways to solve such a problem and to provide a convenient decision support system. We decided to apply a special form of artificial intelligence, genetic algorithms, because they can be very efficient for this type of problems.

4 GENETIC ALGORITHMS

4.1 *Basic principles*

Genetic algorithms (GA) are a class of evolutionary algorithms, based on analogy to the evolution theory. The principle is fairly simple: Survival of the fittest. They are used to solve optimisation problems, especially problems with a hardly known structure or problems with a large number of possible solutions. The search for the best solution is heuristic, not all solutions have to be calculated.

Genetic algorithms use a terminology derived from the biology: an *individual* represents one solution and can be described by one *chromosome*. A chromosome itself can be divided into parts, the so called *genes*. The value of a gene is called *allele*.

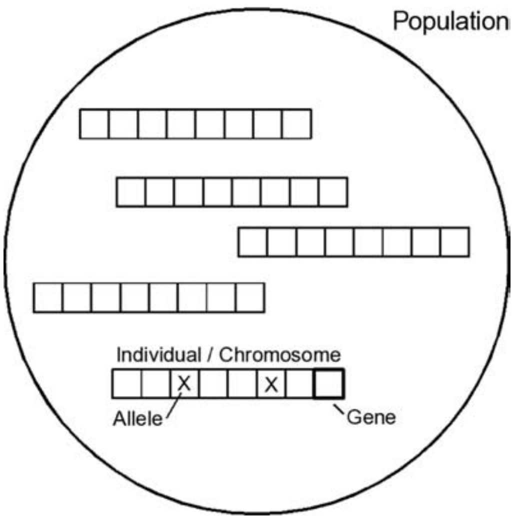

Figure 4. A population of a genetic algorithm.

A *population* contains a certain number of individuals (figure 4). This size of the population always stays the same. The first *generation* of a population is created randomly within the permitted boundaries. The *environment* then computes the *fitness* of each individual on the basis of a fitness function. The fitness function $f : S \rightarrow R$ is a mapping and assigns a real value to each solution in the search space S, the higher the better. The optimal solution $s \in S$ has the maximal fitness of all possible solutions:

$$f(s) = \max\{f(x) \mid x \in S\} \quad (3)$$

The optimisation process to find the best solution is an iterative process. One step of the iteration is called *reproduction* and produces the next generation of a population. This step is repeated until a sufficiently good solution is found. The reproduction itself consists of 3 steps: *selection*, *mutation* and *recombination*.

Selection is the choice of a certain number of individuals of the current generation, which are used to build the next generation. Several mechanisms of selection are possible, e.g. the choice of the fittest individuals. More common though is a random selection with probabilities p distributed linearly to the fitness f, meaning that the weakest individual can also be selected, but the chance is small. In formula 4, s represents an individual, a solution, and n the number of individuals in the population.

$$p(s_i) = \frac{f(s_i)}{\sum_n f(s_j)} \quad (4)$$

A combination of different selection mechanisms is possible. Furthermore, multiple selections of the same individuals can be allowed.

Mutation and recombination are called genetic operators. Mutation can change the alleles of a chromosome. For every gene, it is randomly determined, if the allele is changed and, if so, to what.

Recombination is also called crossover-operation. It takes two chromosomes and randomly interchanges parts of these chromosomes.

The collaboration of selection, mutation and recombination must be carefully coordinated in order to produce the correct amount of individuals, and preferably many different.

The steps of calculating fitness and reproduction to create a new generation must be repeated a numerous amount of times. In each iteration, new and hopefully better individuals are created, but there is no guarantee for an improvement of the population. Degradation is possible. Thus, criteria for the *abortion* of the iteration are needed. There are mainly 3 possible conditions:

1) A certain predefined generation has been reached
2) There is no improvement compared to previous generations
3) The improvement is smaller than a defined value

Combinations of these criteria are possible. The quality of the found solutions depends on the structure of the problem and the chosen parameters for the genetic algorithm.

4.2 *Genetic Algorithms applied to a Petri net*

Simulating material flow in a Petri net involves a numerous amount of possible flows, of possible solutions. Their quantity increases exponentially over time. Genetic algorithms are suitable to find a good solution out of a large number of possible solutions.

In the simulation, time progresses in discrete time steps. In every time step, the user has to decide, which transitions are fired. The user can choose an arbitrary number of transitions, which are not in conflict with each other. Choosing none is also an option. Furthermore, some transitions can transport different amounts of tokens, which increases the total amount of possibilities.

One discrete time step is represented by one gene. The identifiers of the fired transitions with the related amount of tokens are saved in the gene. The order does not make a difference, because they are not in conflict with each other and executed within the same time step. All time steps from the current point to the end of the simulation form one individual.

The first generation of individuals is created randomly: Each individual starts out as a clone of the Petri net with its current state. Then, random transitions to be fired are chosen for each individual in every time

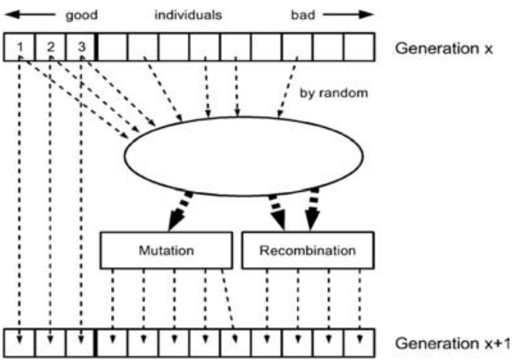

Figure 5. Reproduction.

step. The probabilities are distributed evenly among all active transitions and the choice of no transition to be fired. This selection is repeated until one of two possible conditions occurs: either there are no active transitions anymore or the random generator chooses not to fire a transition. Then the algorithm continues with the next time step. The computing can be parallel for the autonomous individuals.

At the end of a simulation, the individual is evaluated by the fitness function. The fitness of one individual depends only on the final state of the Petri net and is a weighted linear combination of the benefit in form of transported material, costs, and the reliability of the material flow.

$$f(s) = [g_m m(s) - g_c c(s)] g_r r(s) \quad (5)$$

In formula 5, f is the fitness of a solution/individual s. m is a weighted sum of the transported material, c the sum of the costs, and r the total reliability with a value between 0 and 1. g_m, g_c and g_r are weights.

The next generation of the population is then created in the iterative process of reproduction. This co-operation of selection, mutation and recombination has to be calibrated carefully. The possibilities are almost unlimited, but little changes can have huge consequences.

Our process of selection always keeps the best three individuals. Other individuals are randomly chosen (with a probability according to their fitness) and then mutated or recombined. Multiple selections of the same individual are allowed (figure 5).

The genetic operators (mutation and recombination) work with a priority system: a small percentage of the new population originates only from the best three, the rest from the other selected individuals.

If an individual is chosen for mutation, the process randomly selects time steps of an individual. The characteristics of these time steps are then changed, again by random: some originally fired transitions are not executed anymore; other transitions are newly added to the list of fired transitions.

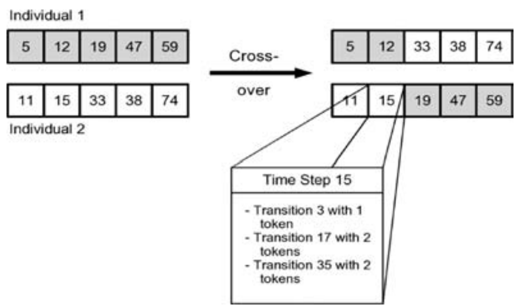

Figure 6. Recombination.

The process of recombination is also called crossover-operation. Two individuals are selected, and parts of the chromosomes are interchanged, all randomly again (figure 6).

The main challenge of this adaption of genetic algorithms to Petri nets is that the genetic operators cause inconsistencies in the state of the net. Since every state derives from prior states and the previously fired transitions, they cannot be exchanged arbitrarily. An individual could list transitions to be fired that cannot be fired. Thus, control and correction are necessary. An algorithm checks the listed transitions in every time step from the beginning of the simulation to the end and eliminates those that cannot be fired.

The process of optimisation is aborted after three consecutive generations without improvement of the best three individuals. We also limit the maximum number of generations in order to avoid infinite loops, which should not occur under normal conditions.

5 FIRST RESULTS AND PERSPECTIVE

The basic idea to adapt genetic algorithms to a Petri net has proven practicable. The problem of inconsistencies caused by the genetic operators is solved, and the approach hence guarantees to provide a permitted solution in an efficient amount of time. At the actual state of our work however, the range of the solutions still varies to a considerable degree. The quality and reliability of the solution strongly depend on the following parameters: number of individuals, fitness function, criteria for reproduction and abortion.

With a too high quantity of individuals, for example, good solutions are too infrequently combined with other good solutions. The population does not improve fast enough or not at all. With a too low quantity, there is not enough diversity and the search for the best solution can become one-directional. The parameters of the genetic algorithm are dependent on each other and their combination involves many options. If these values are not chosen correctly, the algorithm can converge early to a local optimum and provide a bad solution.

Therefore, we are currently studying the influence of the different parameters. It emerges that the parameters of the genetic algorithm have to be in relation to the properties of the Petri net, the number of transitions and tokens. A context adaptive, preferably automated calibration is required. We are confident to find a good solution in order to optimise the material flow in a Petri net and thereby provide a sensible decision support.

After validating the reliability of the solutions, an automatic optimisation of the material flow can be achieved.

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Consistent reconciliation of divergent project schedules under semantic & functional constraints

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ABSTRACT: Coordinating a large program such as the Olympic Games, building a new skyscraper, power station or oil refinery, manufacturing an airplane are challenging problems reliant for success on planning, scheduling and controlling of project activities by all parties involved in the program. Traditional methods like Gantt charts, Critical Path Method (CPM), and the Program Evaluation and Review Technique (PERT) have significant limitations in the case of such large projects which have to be managed concurrently by multiple teams of distributed participants. In the paper presented, an all-embracing reconciliation method is considered and applied to the collaborative project scheduling problem. The main focus is placed on semantic and functional constraints specific to the scheduling problem and on systematic ways to detect and to resolve conflicts in concurrently developed project schedules. The advantages achieved are mathematically strong guarantees of consistency and correctness of the converged schedule representations, a capability to manage them concurrently as well as the avoidance of combinatorial explosion peculiar to all other approaches.

1 INTRODUCTION

Coordinating a large program like the construction of any capital asset such as a refinery, airport, skyscraper or airplane is a challenging problem reliant for success on planning, scheduling and controlling of project activities by all parties involved in the program. Stakeholders own individual tasks, plans, and trade expertise, and yet still need to organize each activity in a way that delivers a shared program goal (Boskers & AbouRizk 2005).

Tools to aid in project scheduling based on activity durations and precedence relationships have existed for some time. Such tools include Gantt charts, Critical Path Method (CPM), and the Program Evaluation and Review Technique (PERT) (Moder et al. 1983) and are so well understood that they are incorporated in most, if not all, popular project scheduling software systems such as MS Project, Primavera, and Time Line. A survey of available CPM solutions from more than 20 software suppliers can be found in (PC Magazine 1995).

However, these tools have significant limitations in the case of large projects which need to be managed concurrently by multiple distributed parties. Hierarchical decomposition of a whole project into subprojects and redistribution of responsibility for separate subprojects among participants is a traditional approach for managing complex projects. Nevertheless, there remain principal factors that create shortcomings in this approach.

1.1 *Collaborative project planning*

The first factor is the concurrent nature of team working. To analyze multiple alternative schedules and to explore various issues of the developed project, individual participants usually prefer working in relative isolation on the optimistic assumption that all potential problems can be resolved after they have emerged.

This is a typical example of optimistic replication recently appearing in such domains as collaborative workspaces, concurrent engineering environments, software configuration solutions, mobile databases, distributed services (Saito & Shapiro 2005). Sacrificing underlying ACID (atomicity, consistency, isolation, and durability) principles, which the traditional database management systems rely on, optimistic replication enables higher availability, performance and productivity (Ramamritham & Chrysanthis 1997). The benefits are reached through reduced latency by letting users and applications share data simultaneously. Instead of synchronous replica coordination deployed in pessimistic transaction models, optimistic methods let data be accessed without a priori blocking but with additional care to reconcile concurrent changes by detecting and resolving occasional conflicts if they happen.

1.2 *Schedule consistency and correctness managing*

The second factor is a need to manage schedule consistency and correctness in collaborative working. An availability of deep semantic and functional relationships among data units makes the adoption of the optimistic replication approach a nontrivial problem. Indeed, concurrency benefits come at a cost, since there is a trade-off between data availability and consistency commonly the case for all distributed systems (Anderson et al. 1998). Optimistic replication inevitably forces divergence of replicated data, emergence of conflicts between concurrent operations and disturbance of the resulting data consistency. These issues are especially critical for collaborative planning problems that proceed on complex multidisciplinary model data and need comprehensive analysis of all sorts of semantic and functional relationships during the necessary reconciliation process.

1.3 *Contributions*

In the paper presented, a general-purpose reconciliation method is considered and applied to the collaborative planning problem. Initially the method was developed and successfully proved for collaborative engineering problems facing the needs to permanently maintain the semantic consistency of concurrently elaborated artifacts (Semenov 2007a, b). Here the main focus is placed on functional constraints specific to the scheduling problem and on systematic ways to detect and to resolve timing conflicts in concurrently developed project schedules.

The research undertaken shows that the basic principles of the method such as support of emerging standards STEP (ISO 1994) and OMG MDA (OMG 2007), analysis of optimistic transactions using formal specifications of underlying data models, logic deduction targeted on the construction of the most promising reconciliation plans, all contribute to the problem solution. The method allows keeping project schedule data in a semantically consistent and a functionally meaningful state by detecting and resolving the conflicts in a holistic framework of true collaborative interaction (Klein 1991).

The paper proceeds as follows. Section 2 presents a general-purpose reconciliation method, its key elements and stages like specification of data and constraints, comparative analysis of divergent replicas, establishment of dependence, precedence and composition relations among changes and logic deduction of reconciliation plans. Section 3 introduces a formal information model for collaborative planning applications and details the character of occurred semantic and functional constraints. We explain here how formal analysis of specifications of an underlying data model can facilitate establishing the relationships of concurrent changes, deducing reconciliation plans and obtaining semantically consistent and functionally correct convergent schedule representation. The provided examples illustrate practical usage of the method and the importance of considering both semantic and functional constraints. In conclusion we summarize the results obtained and outline promising directions for future investigations. The achieved advantages motivate and make possible the implementation of the method in the scope of general-purpose collaborative environments with the advanced facilities to concurrently manage data within strong consistency and correctness requirements.

2 MODEL-DRIVEN RECONCILIATION

Systems supporting concurrent development models have existed for a long time. Today, more than ever, concurrent development is crucial to productivity and optimistic replication technologies increasingly play an important role. According to the optimistic replication principles, applications running within distributed systems are either in isolated execution phase or in the reconciliation phase. In isolated phase the applications proceed on local replicas of the shared data bringing them to some tentative states. All the actions undertaken are recorded in transaction logs that are partially ordered sets of locally applied operations. Actions are assumed to be deterministic and conversable. Replaying a log against the initial state results in the final state. Replaying conversable operations of the log in inverse order returns the final data to initial state. Often, distributed systems exploiting optimistic replication do not support transaction logs. Instead of maintaining the logs permanently, they reconstruct logs (or compute deltas) as necessary by means of matching and differing original and tentative data states. At the reconciliation phase the concurrent transaction operations (or delta chunks) are analyzed against potential conflicts and brought to convergent states by resolving the detected conflicts.

2.1 *Information modeling issue*

So far, there is no common understanding of what constitutes the conflicts nor how to identify and to resolve the conflicts in a general case. In further consideration the conflicts are interpreted as incidents of the combined acceptance of concurrent operations having one of the following results:

- consistency and correctness of the resulting data are disturbed due to violation of semantic and functional constraints,
- operations could not be correctly applied in accordance with predefined semantics,
- reconciliation process admits multiple solutions are needed for subsequent selection.

To differentiate the consistency and correctness of the data, the corresponding concepts are defined below.

Definition 1. A data $X \in M$ driven by the information model M is called consistent only if all the semantic rules $S \subset M$ are satisfied on the given data set X.

Definition 2. A consistent data $X \in M$ driven by the information model M is called correct only if all the functional constraints $F \subset M$ are satisfied on the given data set X.

Semantic relationships are constraints imposed upon data to satisfy necessary consistency requirements. Satisfying semantic constraints implies that the data representation is valid and can be interpreted in some way adequate to the information model defined. In particular, the consistent schedule data are suitable for the CPM method to be applied and critical activities chains to be determined. Violation of any semantic rule and disturbing the consistency would result in the losing of data usefulness for any further elaborations.

Functional relationships are usually constraints induced by application functions. Obeying functional constraints makes the data meaningful for practical purposes. As an example, traditional project planning systems enable users to form appropriate schedules under multiple timing constraints like project milestones, activity precedence dependencies, preferences of early or late of execution of activities. Satisfying functional constraints implies that any considered problem has been correctly stated and resolved under the conditions specified. Violation of any functional constraint would mean that the data are still in unresolved state and needs either the restatement of the initial problem or the refinement of partial solutions already found.

Sometimes functional constraints are of multidisciplinary character encompassing every variety of data types and units. So, to satisfy global requirements of project correctness while obtaining meaningful results, the scheduling process must involve whole project work breakdown structures as well as take into account commonly imposed requirements such as leveling resources, minimizing expenses, and reducing risks (Meredith & Mantel 1995).

Both semantic and functional rules can be specified formally in such information modeling languages as EXPRESS (ISO 2004), UML/OCL (OMG 2006). These object-oriented languages provide a wide range of declarative and imperative constructs to define both data structures and constraints imposed upon them. Constraints typically appeared in applications are categorized and enumerated below. The presented categories cover constraints imposed upon primitive data types (character, string, integer, float, double, boolean, logical, binary), collection types (set, multiset, sequence, array), and object types:

- value domains for primitive data types;
- limited widths of strings and binaries;
- size of collections;
- uniqueness of elements in sets;
- ordering of elements in sorted collections;
- mandatory elements in arrays;
- cardinality of object populations;
- uniqueness of attribute values (optionally, their groups) on object type extents;
- mandatory attributes in objects;
- multiplicity of direct and inverse associations in objects;
- cycling of associations on object type extent;
- value domains restricting and interrelating states of separate attributes, objects and whole object populations. Value domains can be specified in general algebraic form by means of all the variety of imperative constructs available in the modeling language (control statements, functions, procedures, etc.).

Certainly, each application domain proceeds on particular data models with specific semantic and functional rules. Therefore, the method discussed follows a model-driven paradigm admitting that the underlying data model might be a comprehensive formal basis not only to define and validate application-specific rules, but also to identify and to resolve particular conflicts. Thereby the general-purpose reconciliation method is based on a mathematically solid foundation and allows effective implementations for solving similar problems arising in different application domains.

2.2 *Reconciliation method*

The method is presented by following a trustworthy "three-way merge". This is a key technique that many researches have to address (Lindholm T. 2003). It generally serves to combine the changes made to a versioned data set in two parallel branches. It requires a common ancestor version X to be identified, and works by computing deltas $\Delta' = Delta(X', X)$, $\Delta'' = Delta(X'', X)$ from the ancestor X to derived versions X', X'' elaborated concurrently. The deltas are structurally represented as sets of chunks $\Delta' = \{\delta'\}$, $\Delta'' = \{\delta''\}$ each of which corresponds to basic transaction operation. In conformity to acknowledged object-oriented methodology these operations are to create an object *new*(*obj*), to delete it *del*(*obj*), to move an object *move*(*obj*), and to modify its attribute *mod*(*obj.attr*). The delta chunks are then combined to produce a merge delta $\Delta^* = Merge(\Delta', \Delta'')$, which being applied to the common ancestor X, yields the desired result: $X^* = Apply(X, \Delta^*)$.

Trivial merge functions like $Merge(\Delta', \Delta'') \equiv \emptyset, \Delta', \Delta''$ are not of interest since they result in already available solutions X, X', X'' correspondingly. A more valuable result could be obtained in consolidating chunks from both deltas and reconciling divergent versions. So, it would be interesting to form merge function so that maximum degree $|Merge(\Delta', \Delta'')|$ is reached on the sets Δ', Δ''. In the ideal situation we could accept merge function as $Merge(\Delta', \Delta'') \equiv \Delta' \cup \Delta''$ to achieve that. Nevertheless, separate chunks in the deltas may conflict with each other preventing correct mutual execution and disturbing the correctness of the final representation. To avoid this, the conflicting chunks have to be removed from the merge delta.

Following semantic and functional interpretation of the conflicts, the method presented combines both a natural principle of consolidation of concurrent transactions and necessary requirements of consistency and meaningfulness for the solutions. Here we don't intend that each operation would maintain the data correctness, but require the whole reconciled transaction to have the correct result.

On condition that original versions X, X', X'' are consistent and meaningful, the method allows the formation of a solution $X^* = Apply(X, Merge(Delta(X', X), Delta(X'', X)))$ satisfying both consolidation and correctness requirements. The assumption above is a rather reasonable hypothesis about original and tentative states motivated by trustworthiness of the applications proceeding on local data replicas and running on local machines in isolated mode. In such consideration we try to narrow the explored domain of deltas guaranteeing the correctness of the result.

Definition 3. A delta Δ^* is called semantically coherent to the version X only if all operations $\delta \in \Delta^*$ can be evaluated correctly and the resulting version $X^* = Apply(X, \Delta^*)$ satisfies all the semantic constraints defined by the information model.

Definition 4. A semantically coherent delta Δ^* is called functionally coherent to the version X only if the resulting version $X^* = Apply(X, \Delta^*)$ satisfies all the functional constraints defined by the information model.

The definitions imply that if original and derived versions X, X' are semantically consistent, and the delta $\Delta' = Delta(X', X)$ is computed correctly so that $X' = Apply(X, \Delta')$, then the delta Δ' is semantically coherent to the version X. Similarly, if original and derived versions X, X' are functionally correct, then the computed delta $\Delta' = Delta(X', X)$ is functionally coherent to the version X.

The approach reinterprets the reconciliation problem as a problem of forming a merge delta $\Delta^* \subseteq \Delta' \cup \Delta''$ coherent to X from available coherent deltas Δ', Δ''. For that purpose, formal analysis of delta chunks is constructively conducted based on the underlying information model covering both data structures and constraints imposed upon them. The analysis results are dependence, precedence and composition relations established among delta chunks.

The dependence relations are defined using mathematical logics as follows. With each chunk $\delta \in \Delta$, where $\Delta = \Delta' \cup \Delta''$, we connect corresponding logical variable δ^σ. The variable takes true if the chunk must be accepted in producing a final merge delta Δ^* and false if the chunk must be removed from the delta by some reasons. In the notation applied the values 1 and 0 for negotiation status σ correspond to the cases when the chunks are accepted and rejected. In such consideration a vector of logical variables $\{\delta^\sigma\}$ defines a resulting representation for the final delta as a subset of chunks for which negotiation status takes 1. Dependence relations are set among chunks that may belong to the same delta and to concurrent branch deltas. Simple example is an implication relation $\delta_1 \to \delta_2$ connecting a pair of chunks δ_1, δ_2. The relation implies that a merge delta Δ^* must contain δ_2 on condition that it contains δ_1 or in another way $\forall \delta_1, \delta_2 \in \Delta,\ \delta_1 \to \delta_2$: $\delta_1 \in \Delta^* \to \delta_2 \in \Delta^*$. Other sorts of binary relations are induced by known logic operations like equivalence, exclusive disjunction, stroke operation, and Peirce function (Zakrevskij 2003). Dependences both binary and multiple ones need to be proceed in a general way. To represent dependence relations, a reconciliation function is defined using normal disjunctive form:

$$D(\Delta) = \bigvee_{\bar{\sigma}} \delta_{i1}^{\sigma_{i1}} \delta_{i2}^{\sigma_{i2}} \delta_{i3}^{\sigma_{i3}} \ldots, \text{ where } \delta_{i1}, \delta_{i2}, \delta_{i3} \ldots \in \Delta$$

The reconciliation function of multiple logic variables $D(\Delta)$ takes false if the corresponding chunk combination $\{\delta\} \subseteq \Delta$ is admissible and true if the combination is prohibited. Here the conjunctive terms go on all the sets of negotiation statuses $\sigma_{i1}, \sigma_{i2}, \sigma_{i3}, \ldots$, for which particular combinations of chunks violate the imposed dependency relation.

The precedence relations are defined as follows. For chunks δ_1, δ_2, if $\delta_1 \angle \delta_2$ then the chunk δ_1 must appear before (not necessarily immediately before) the chunk δ_2 in any merge delta Δ^* containing both δ_1 and δ_2. The precedence does not imply the existence of the related chunks in the resulting delta, but if the delta contains both chunks then one of them precedes the other. The precedence relation is non-symmetric, non-reflexive, but transitive. So, if relations $\delta_1 \angle \delta_2$ and $\delta_2 \angle \delta_3$ are established among $\delta_1, \delta_2, \delta_3$, then the relation $\delta_1 \angle \delta_3$ takes place. No matter which chunks are involved in the merge delta in such case.

The composition relations are defined taking into consideration so called “parent-child” relationships. For chunks δ_1, δ_2, if $\delta_1 \in \delta_2$ then a merge delta Δ^* must contain δ_1 on condition that it contains δ_2 as well as the delta must exclude δ_1 on condition that it excludes δ_2 or in another way $\forall \delta_1,\ \delta_2 \in \Delta' \cup \Delta'',\ \delta_1 \in \delta_2$: $\delta_2 \in \Delta^* \rightarrow \delta_1 \in \Delta^*$, $\delta_2 \notin \Delta^* \rightarrow \delta_1 \notin \Delta^*$. In contrast to primitive chunks that can be of inclusion or exclusion status only, composite chunks may take also indefinite status indicating that some child chunks are included in the delta and some child chunks are excluded from it at the same time. Evaluation of composite chunks results in sequential evaluation of all the child chunks with the status corresponding to composite status and in the order induced by previously established precedence relations.

The relations discussed may have strong interpretation assuming necessary character of the induced relationships among chunks as well as weak interpretation meaning their sufficient character. We found that weaker relations are also useful to reproduce important use cases occurring in replication scenarios. Such relations can be easy analyzed and, if necessary, can be omitted from the consideration. Nevertheless, since risk of disturbing the data correctness remains, the reconciled results have to be additionally validated against constraints for which the induced weak relationships were neglected.

2.3 *Formal analysis of concurrent transactions*

Systemize formal ways according to which the dependence relations are established among concurrent operations. For brevity only typical sorts of semantic and functional constraints are considered here assuming that the underlying data model may define other constraints too. The considered sorts are referential integrity, optional and mandatory attributes, composition, concurrent modification, equivalent operations, collection multiplicity, and algebraic inequality that typically arise in planning applications (in more details discussed in the next section).

Referential integrity. Let a chunk $\delta_1 \in \Delta$ creates new object and a chunk $\delta_2 \in \Delta$ sets an association to the created object. To guaranty the referential integrity, the dependence must be established with the reconciliation function below:

$$D(\Delta) = \overline{\delta}_1 \delta_2$$

If the chunk $\delta_2 \in \Delta$ resets available association to existing object and chunk $\delta_3 \in \Delta$ deletes it, then additional dependence must be imposed with the function:

$$D(\Delta) = \delta_3 \overline{\delta}_2$$

Mandatory attribute. Let a chunk $\delta_1 \in \Delta$ creates an object and chunk $\delta_2 \in \Delta$ initiates its mandatory attribute (or association). Then the following dependence must be established:

$$D(\Delta) = \delta_1 \overline{\delta}_2 \vee \overline{\delta}_1 \delta_2$$

Optional attribute. Let a chunk $\delta_1 \in \Delta$ creates an object and $\delta_2 \in \Delta$ initiates its optional attribute (or association). Then the dependence relation is represented as follows:

$$D(\Delta) = \overline{\delta}_1 \delta_2$$

Composition. Composition is a special kind of the association relationship between parent and children objects. Therefore, all the previous cases may relate to compositions too. The only dependency induced by the composition must be taken into analysis additionally:

$$D(\Delta) = \overline{\delta}_1 \delta_2$$

Here the chunk $\delta_1 \in \Delta$ creates a parent object and $\delta_2 \in \Delta$ creates its children object. If a chunk $\delta_3 \in \Delta$ deletes a parent object and $\delta_4 \in \Delta$ deletes its children object, then the dependency takes the form:

$$D(\Delta) = \delta_3 \overline{\delta}_4$$

Concurrent modification. Let chunks $\delta 1$, $\delta_2 \in \Delta$ modify the attribute (or association) of the existing object in different branches. Then the dependence is represented as follows:

$$D(\Delta) = \delta_1 \delta_2$$

Similar dependence is established if one of the chunks modifies an object and another deletes it.

Equivalent operation. Let chunks δ_1, $\delta_2 \in \Delta$ correspond to equivalent operations in different branches. For example, this case occurs in deleting of the same object in concurrent branches. Then reconciliation function must be formed in such way to exclude accepting one operation in rejecting another. The dependence relation looks as follows:

$$D(\Delta) = \delta_1 \overline{\delta}_2 \vee \overline{\delta}_1 \delta_2$$

Collection multiplicity. Let chunks $\delta_1, \delta_2, \ldots, \delta_I \in \Delta$ add and remove elements in/from a collection for that an underlying data model defines multiplicity constraint in the form: $n \leq collection.size \leq m$. No matter what the collection data is. It may be a collection of objects or a collection of primitive or structured data being object attribute. Denote a subset of indices for adding operations as $I^+ \subseteq I$ and a subset for removing operations as $I^- \subseteq I$ so that $I^+ \cup I^- = I$. Then the constraint induces a perfect disjunctive form to represent impossible combinations of chunks:

$$D(\Delta) = \underset{\tilde{\sigma}}{\vee} \delta_1^{\sigma_1} \delta_2^{\sigma_2} \ldots \delta_I^{\sigma_I}, \textit{ where } \tilde{\sigma} = (\sigma_1, \sigma_2, \ldots, \sigma_I):$$
$$n \le collection.size + \sum_{i \in I^+} \sigma_i - \sum_{i \in I^-} \sigma_i \le m$$

Here the conjunctive terms enumerate all the sets of negotiation statuses $\sigma_1, \sigma_2, \ldots, \sigma_I$, for which the multiplicity constraint is violated. If multiplicity has been fixed for the collection type, the number of added elements must equal to the number of removed elements and, therefore, disjunctive form takes the form:

$$D(\Delta) = \underset{\tilde{\sigma}}{\vee} \delta_1^{\sigma_1} \delta_2^{\sigma_2} \ldots \delta_I^{\sigma_I}, \textit{ where } \tilde{\sigma} = (\sigma_1, \sigma_2, \ldots, \sigma_I):$$
$$\sum_{i \in I^+} \sigma_i = \sum_{i \in I^-} \sigma_i$$

Algebraic inequality. Often, an imposed algebraic constraint is given by a predicate function of multiple real variables in the form $f(x_1, x_2, \ldots, x_n) \le 0$. If variables are changed in both concurrent branches, there is a trivial way to set weak dependencies as exclusion between two equivalence groups corresponding to all chunks of each branch. It directly follows from assumption about the coherence of deltas. Nevertheless, there is a possibility to set strong dependence as follows:

$$D(\Delta) = \underset{\tilde{\sigma}}{\vee} \delta_1^{\sigma_1} \delta_2^{\sigma_2} \ldots \delta_k^{\sigma_k}, \textit{ where } \tilde{\sigma} = (\sigma_1, \sigma_2, \ldots, \sigma_k):$$
$$f(x_1 + \sigma_1 \Delta x_1, x_2 + \sigma_2 \Delta x_2, \ldots, x_k + \sigma_k \Delta x_k) \ge 0$$

Here k — a number of changed variables. Formation of the reconciliation function $D(\Delta)$ for this type of constraint may be a computationally expensive routine requiring 2^k evaluations of the predicate function. If the predicate function is represented in the additive form:

$$f(x) = f_0 + \sum_{i=1}^{n} f_i(x_i)$$

the complexity of the analysis can be decreased significantly due to preliminary sorting of the function increments and excluding of redundant evaluations when a verdict can be determined from the already obtained results.

2.4 *Logic deduction*

Once the relations are defined, logic deduction methods, in particular, poly-syllogistic methods, can be applied to form the merge delta $\Delta^* \subseteq \Delta' \cup \Delta''$ coherent to X. The determination of equivalence classes of chunks and implication chains simplifies the logic analysis and allows the formation of promising reconciliation plans satisfying both consistency, meaningfulness and consolidation requirements. It can be done automatically in accordance with assigned reconciliation policy or interactively giving the user an opportunity to take subsequent decisions and to control obtained results. For more details see the works (Semenov & Karaulov 2006).

3 APPLICATION

3.1 *Schedule data model*

In the research presented focus is placed on a traditional network technique — CPM method often used in scheduling projects. CPM was originally developed in the 1950's by the DuPont Company and Remington Rand Univac for managing plant maintenance and construction work (Melin & Whiteaker 1981). Recently, the method has been used in large and complex projects consisting of thousands of interrelating activities. Following this method, the project is visually represented as a network diagram depicting activity durations and their precedence relationships. Based on the network representation the method enables ultimately the determination and display of the critical path — chains of activities most sensitive and determinant to overall project duration.

Being computerized in more than 30 scheduling systems, the method depended on generalizations. In particular, various timing constraints are allowed to impose directly on activities as well as different types of precedence links are supported to help specify interrelated activities in a more adequate way. Therefore, to a significant extent the scheduling problem can be considered as a constraint-based problem. Accordingly the found solution gives start values for activities satisfying all the imposed timing constraints and precedence relations. The survey mentioned above showed that most routines had specific applications and were adapted to specific computer platforms. None were ideally suited nor could be reasonably modified to meet the needs of collaborative problems. Therefore, the method presented here is of special interest and transforms collaborative planning.

Let us consider the scheduling problem from the information modeling point of view. Following object-oriented methodology (Rumbaugh et. al. 1991) let a schedule X is a tuple $X = \{A, C, R\}$, where A, C, R are finite sets of activities, timing constraints and precedence relations. Project start and finish are defined by timing attributes of the schedule *X.start* and *X.finish*. Each activity $a \in A$ has its own attributes *a.code*, *a.start*, *a.dur* meaning unique user identifier, start date and duration.

Each constraint $c \in C$ defines a timing interval or semi-interval the target activity *c.target* must start or finish on. The interval limits are defined by attributes *c.low*, *c.high*. Taking the values *Begin* or *End*, the attribute *c.region* specifies the activity region (start or finish) the constraint applies to and, thus, allows to cover all use cases typically arisen in the applications: *start-on*, *start-after*, *start-before*, *start-between*, *finish-on*, *finish-after*, *finish-before* and *finish-between*. Additional optional attribute *c.alignment* refines whether the target activity is evaluated as soon as possible (*ASAP*) or as late as possible (*ALAP*) on condition that some float is admitted by the schedule.

Each relation $r \in R$ interconnects associated preceding and succeeding activities *r.predecessor* and *r.successor* by evaluating the timing lag *r.lag* between them. Interconnection type *r.type* takes one of the values: *FS*, *FF*, *SS*, and *SF* pointing out which regions of the activities are connected and what timing interval is implied.

Semantic rules are constraints imposed upon model-driven schedule data to satisfy necessary consistency requirements. Satisfying semantic constraints implies that the schedule data representation is valid and can be interpreted in some way adequate to the information model defined. In particular, the consistent schedule data are suitable for the CPM method to be applied and critical activities chains to be determined. Violation of any semantic rule and disturbing the consistency would result in the loss of data sense for further elaborations.

Functional rules are constraints the schedule must obey to be meaningful for practical planning purposes. Satisfying functional constraints implies that the scheduling problem has been correctly stated and resolved under the conditions specified. Violation of any functional constraint would mean that the stated problem could not be resolved due to conditions over-defined or failure of the CPM method applied.

Based on the overall project start and finish, individual activity durations and precedence relations, classic CPM method performs the forward pass to calculate early start and early finish and the backward pass to calculate late start and late finish. Then it takes their differences to calculate the free float for each individual activity, the total float of the paths through the network, and ultimately to determine and to display the critical path — chains of activities that determine overall project duration. It should be noted that negative value for the calculated total float would mean that the project cannot be correctly scheduled under overall project start and finish times and imposed timing constraints, zero value — project can be completed exactly on finish time and positive value — there is some float for the project completing.

The described information model can be specified at the EXPRESS modeling language in a formal way to represent schedule instances and to implement classic CPM method (Fig. 1). The presented schema defines the entities *SCHEDULE*, *ACTIVITY*, *RELATION*, and *CONSTRAINT* corresponding to the introduced above model concepts and provides additional specifications for the derived properties, inverse associations and rules.

In particular, early start *ES* and late finish *LF* are reserved as optional *ACTIVITY* attributes intended for the CPM computations. Derived attributes like finish date *finish*, late start *LS*, early finish *EF*, and free float *FF* assume to be immediately recomputed using the specified formulas. Inverse associations *incomings* and *outcomings* enable one to know all the relationships the given activity is involved in. The inverse association *sched* gives the opportunity to get parent schedule. Similarly, the inverse association *constr* enables to obtain the constraint if it is assigned to the activity.

The rule *S1* means that values of the project start and finish time must be set so that finish time is not less than start time. The rules *S2*, *S3* can be interpreted as requirements for each activity to have a unique identifier and a preset positive value of the duration. The next *S4*, *S5* rules act as conditions ensuring the timing constraints are correctly defined. At least one of the limits must be set, in the case where both limits are set the low limit must be not greater than the high limit. The rule *S6* requires that preceding and succeeding activities of each relation must be non-coincident. And, finally, the schema defines implicit rules for mandatory attributes and associations. As an example, the correct representation of the *ACTIVITY* entity instances assumes necessary setting the attributes *code*, *start*, and *dur*.

The rule *F1* assumes that all the activities begin after the project start and complete not later than the project finishes. The rules *F2* and *F3* imply that the scheduled activities satisfy all the imposed constraints like milestones and precedence relations and the schedule can be applied for planning purposes.

3.2 *Incremental schedule analysis*

As it was presented, semantic and functional constraints defined by the scheduling data model can be classified in accordance with the general categorizes introduced above. These are referential integrity, optional and mandatory attributes, composition, concurrent modification, equivalent operations, collection multiplicity, and algebraic inequality. It means that the considered formal rules for analysis of concurrent transactions can be applied in full measure to establish dependence relations among concurrent chunks of divergent schedules. Nevertheless, formal

```
SCHEMA SCHEDULING
ENTITY SCHEDULE;
   activities : SET [0:?] OF ACTIVITY;
   relations : SET [0:?] OF RELATION;
   constraints : SET [0:?] OF CONSTRAINT;
   start : OPTIONAL REAL;
   finish : OPTIONAL REAL;
WHERE
   S1 : start <= finish;
END_ENTITY;

ENTITY ACTIVITY
   code : STRING;
   start : REAL;
   dur : REAL;
   ES : OPTIONAL REAL;
   LF : OPTIONAL REAL;
DERIVE
   finish : REAL := start + dur;
   EF : REAL := ES + dur;
   LS : REAL := LF – dur;
   FF : REAL := LS – ES;
INVERSE
   incomings : SET [0:?] OF RELATION FOR predecessor;
   outcomings : SET [0:?] OF RELATION FOR successor;
   sched : SCHEDULE FOR activities;
   constr : SET [0:1] OF CONSTRAINT FOR target;
UNIQUE
   S2 : code;
WHERE
   S3 : dur >= 0;
   F1 : start >= sched.start AND finish <= sched.finish;
END_ENTITY;

TYPE REGION_TYPE = ENUMERATION OF
      ( Begin, End );
END_TYPE;
TYPE ALIGNMENT_TYPE = ENUMERATION OF
      ( ASAP, ALAP );
END_TYPE;
ENTITY CONSTRAINT
   target : ACTIVITY;
   low : OPTIONAL REAL;
   high : OPTIONAL REAL;
   region : REGION_TYPE;
   alignment : ALIGNMENT_TYPE;
WHERE
   S4 : EXISTS(low) OR EXISTS(high);
   S5 : low <= high;
   F2 : IF(region = Begin)
           THEN target.start >= low AND target.start <= high;
           ELSE target.finish >= low AND target.finish <= high;
        END_IF;
END_ENTITY;

TYPE RELATION_TYPE = ENUMERATION OF
      ( FS, FF, SS, SF );
END_TYPE;
ENTITY RELATION
   predecessor : ACTIVITY;
   successor : ACTIVITY;
   lag : REAL;
   type : RELATION_TYPE;
WHERE
   S6 : predecessor :<>: successor;
   F3: CASE type OF
           FS : successor.start >= predecessor.finish + lag;
           FF : successor.finish >= predecessor.finish + lag;
           SS : successor.start >= predecessor.start + lag;
           SF : successor.finish >= predecessor.start + lag;
      END_CASE;
END_ENTITY;
END_SCHEMA;
```

Figure 1. Formal specification of the schedule model at EXPRESS language.

analysis of concurrent chunks potentially disturbing such functional constraints as milestones and precedence relations need some additional explanations and refinements. Both sorts of constraints belong to the algebraic inequality category that assumes the availability of explicit algebraic inequalities. In the case of milestones and precedence relations, they are represented by additive functions of real variables being start dates of activities and their durations. To form a total reconciliation function, it might be effective to carry out incremental analysis of divergent schedules along all the paths undergoing to changes. Then, the total function can be formed as a disjunction of partial reconciliation functions regulating impossible combinations of chunks along separate paths with modified activities.

3.3 *Example*

Consider the collaborative scheduling problem by applying the reconciliation method proposed to two possible statements. The first statement implies that available schedule versions satisfy all the consistency requirements and the same demand is made for the reconciled version too. The second statement takes into account functional timing constraints specific to the scheduling problem in addition to necessary semantic ones. Indeed, if available schedule versions satisfy all the timing constraints, it would be natural to impose similar functional constraints upon the reconciled result as well.

The figure 2 presents replicas of the cooperatively developed schedule — common ancestor version X (Fig. 2a) and derived versions X' (Fig. 2b) and X'' (Fig. 2c) obtained in the first and the second transactions respectively. In the version X' new relationships *r21* and *r13* have been added to position the activity *a1* between *a2* and *a3* as well as durations of the activities *a1* and *a4* have been increased. The relationship *r23* between the activities *a2* and *a3* has been deleted since it becomes redundant in the derived representation. Although these changes lead to critical path extension along the activity chain $a2 \rightarrow a1 \rightarrow a3$, but due to floats available in the original version it has no impact on the milestone *m*, so the derived schedule remains correct. After rescheduling, the schedule X' becomes as it is drawn in the figure. The delta Δ' takes the form $\{new'(r21), new'(r13), del'(r23), mod'(a1.dur), mod'(a4.dur), mod'(a1.start), mod'(a3.start)\}$.

In the version X'' a new activity *a5* has been added with relationships *r45*, *r53* positioning it between the existing activities *a4*, *a3*. The relationship *r43* connecting the activities *a4* and *a3* has been deleted as a redundant one. The relationship *r12* has also been added to position the activity *a2* just after *a1*. Due to the additional activity *a5* in a critical path, rescheduling routine shifted a start date of the activity

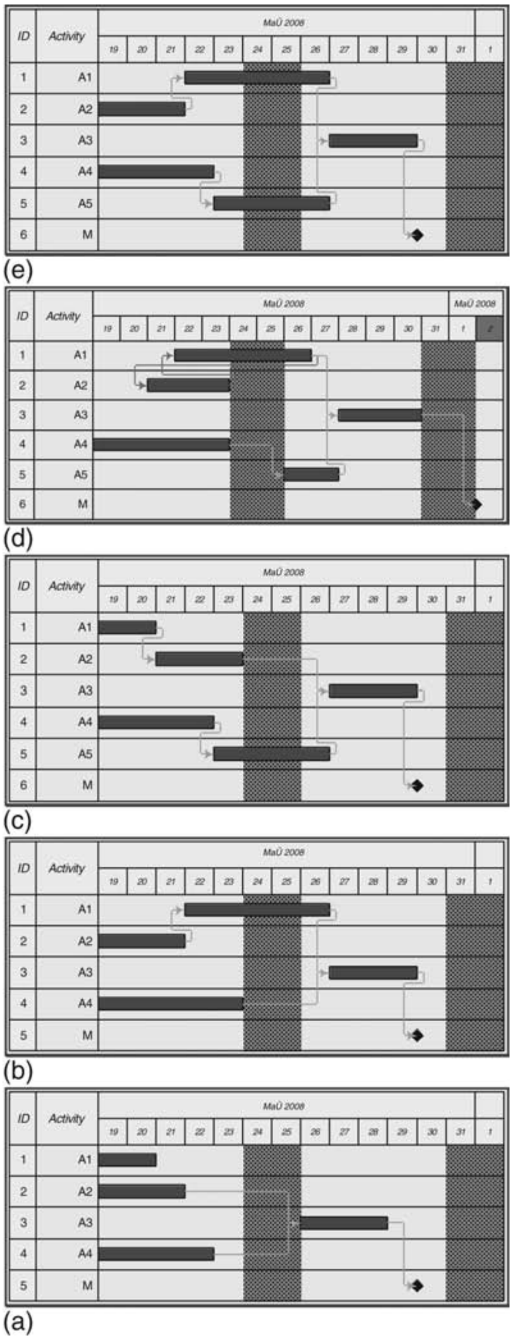

Figure 2. The original replicas and reconciliation results.

a3 in a corresponding value. The delta representation Δ'' takes the form $\{new''(a5), new''(r45), new''(r53), del''(r43), new''(r12), mod''(a2.start), mod''(a3.start)\}$ and the schedule remains to be correct as well.

According to the schedule model (Fig. 1) relationship instances must have the activity associations to be set, hence the relations $new''\ (r45) \rightarrow new''\ (a5)$, $new''\ (r53) \rightarrow new''\ (a5)$ must be satisfied. Direct consolidation of the concurrent deltas detects no conflicts and results in the schedule representation given by the figure 2d. The representation is fully consistent satisfying all the semantic constraints defined by the information model. Nevertheless, it is not correct because it inevitably disturbs the precedence relationships between the activities *a1* and *a2* as well as violates the milestone *m* constraint.

Taking into account the second functional statement, additional logic dependencies can be derived from the rule *F3*:

$\text{new}'(\text{r21}) \rightarrow \text{mod}'(\text{a1.start})$,
$\text{mod}'(\text{a1.dur}) \wedge \text{new}'(\text{r13}) \rightarrow \text{mod}'(\text{a3.start})$,
$\text{new}''(\text{r12}) \rightarrow \text{mod}''(\text{a2.start})$,
$\text{new}''(\text{a5}) \wedge \text{new}''(\text{r53}) \rightarrow \text{mod}''(\text{a3.start})$.

Functional analysis identifies also two conflicts between concurrent deltas. The first conflict appears due to arising cycle of the precedence relationships *r21*, *r12*, so the exclusive relation $new'(r21) \oplus new''(r12)$ must be taken into consideration. The second conflict originates from extension of critical path over the activities *a4*, *a5*, and *a3* and violation of the milestone *m*. To avoid that, the exclusive relation must be satisfied too: $mod'(a4.dur) \oplus new''(r45) \vee new''(r53)$. Resolving the first conflict by taking the changes of the first transaction and the second conflict by taking the changes of the second transaction, we obtain the correct reconciled schedule given by the figure 2e. Note that the given way of resolving the conflicts allows including the maximum number of operations from the concurrent deltas to the resulting one.

Essentially, all the meaningful results above have been obtained in formal ways using semantic and functional analysis of concurrent deltas and applying logic deduction methods.

4 CONCLUSIONS

Thus, the problem of consistent reconciliation of divergent project schedules has been studied and the method for solving it has been proposed and presented. The method enables significant simplification and formalization of the general problem satisfying principles of semantic consistency and functional meaningfulness for resulting convergent representation of the schedule elaborated concurrently. It avoids combinatorial explosion peculiar to many other methods. Due to formalization achieved the method can be implemented within various collaborative environments. This work is planned for the near future.

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Architect's decision station and its integration with project-driven supply chains

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ABSTRACT: Sustainability poses challenges to building design as it requires the use of multiple and interrelated sources of knowledge and expertise. This paper posits similarities between the building design process and supply chains established on an *ad hoc* basis. The supply chain is project-driven and this needs to be reflected by the associated information network that is used by all members of the chain. From the perspective of the architect and other participants the information environment they function in is complex and dynamic. Their decision-making can be supported with decision stations that are situated in the environment and capable of providing active and comprehensive support. The architecture of the decision station and its situating in the information environment is presented. The stations associated with the project participants form a project-specific network. Its effective functioning depends on the use of multiple ontologies, which make effective communication possible. Decision stations' situatedness, the network, its nodes and the local environments, and the ontologies are illustrated by examples.

1 INTRODUCTION

Design of buildings has always been a complex process involving specialists from such areas as structure, heating and cooling, natural and artificial lighting, wiring, plumbing and water mains, and accessibility.

The difficulties in designing have buildings increased significantly with the social responsibility imposed on the architects. Architects are expected to design buildings with high degree of sustainability and very low environmental impact. New solutions proposed by the industries and experts, overwhelming information, changing environmental, legal and political contexts (Bossink 2007), and other uncertainties add to the complexities architects face.

In effect both the architects and the domain experts need to collaborate in order to learn about the most recent developments in all areas related to building design (Malkawi 2004). This includes examining specific solutions and their inter-dependencies with both the existing as well as the new components.

Such interrelated factors as global warming, volatile weather conditions, and social interest in sustainable development impose considerable pressure on building designers and developers to construct green buildings. These factors, in turn, have led to a large number of new solutions (Omer 2008), including building materials and technical components.

Information about these solutions is available but highly dispersed. In addition to the trade magazines and shows, the most popular and accessible source is the web, due to the information currency and the ability of accessing documents at any time and place.

The underlying assumption for this work is that building design and construction like many other human undertakings takes place in an electronic environment that is dynamic and heterogeneous. The effective use of information dispersed on the web requires new type of decision support that provides tighter integration and higher degree of direct interaction with the problem domain. But – as Simon (1960) notes – people have quite limited information processing capacity and when the problems are complex they need to decompose them into smaller parts and distribute among other persons. Consequently, building design is distributed among domain experts, who may have to involve other experts and builders.

The building design decentralization is a known and established practice. In recent years, however, in addition to the complexities mentioned above, the associated involvement of more experts and the frequent deepening of the collaboration from only two levels (architect and domain experts) to three and more levels introduced new challenges (Gangemi, Malanga et al. 2000).

The process of designing buildings shares many similarities with that of supply chains which involve the flow of products and services from their source nodes through intermediary nodes where they are assembled and aggregated to the final node where final product or service is delivered (Love, Irani et al. 2002)[1]. Viewed as a supply chain the source and intermediary nodes may propose various partial solutions in building design which are tested and integrated in the intermediary nodes leading to the complete design in the final, architect node.

In this paper we propose a comprehensive solution that integrates information and communication technologies (ICT) to support the work of the supply chain members in building design. The solution is leveraging the opportunities provided by the web and semantic web, and relies on the internet technologies in the construction of systems for all participants of the supply chain.

The supply chain may be established on an *ad hoc* basis and change from project to project. The characteristics of the supply chains established by an architect are discussed in Section 2. The ICT-based system that is capable of supporting both the architect and other members of the supply chain is presented in Section 3. The basic adopted system concept is "decision station" (DS), (Vahidov 2002), and it is the main building block of the information network that is used by the supply chain. In order to provide the flexibility necessary due to the nature of an *ad hoc* supply chain, DSS need to be situated in their environment. Section 4 presents the concept of situating architect's DS.

There are several key issues associated with the project-driven DS integration. The architecture and main functions of the DS network are presented in Section 5. The functioning of this network is illustrated with an example coming from the architectural design. The issues associated with the DSS ability for effective communication and the related use of multiple ontologies are also discussed and illustrated with examples in Section 6. Section 7 concludes the paper and discusses future work.

[1] We use the "supply chain" metaphor because of the involvement of different autonomous organizations rather than individuals and teams coming from the same organization

2 SUPPLY CHAIN AND DECISION SUPPORT

Supply chain management requires the resolution of issues at both strategic and operational levels. At the strategic level decisions about the construction of selection mechanisms for organizations participating in any given process have to be made. Depending on the project different partners may be needed, for example, it is probable that the architect would select one group of partners for the design of a seaside resort and another group for a tall office building. This selection may be further complicated with the requirement that different criteria should be used at different levels of the supply chain. For example, at the high level, the partner's experience and reliability may be the most important, while at the lower levels costs and delivery time may be the key criteria. At the operational levels issues such as production planning and logistics need to be addressed.

The above shows that effective management of a supply chain is difficult. If the environment is dynamic and complex, as it maybe the case with some design projects, then decision support systems may be very useful.

The difficulty is, however, that traditionally these systems have been designed for highly complex but stable problems. These systems also did not explicitly consider the relationship between the decision problem and its context, the implementation environment, and the users' need for active rather than passive support. Several theoretical and applied efforts have been undertaken over recent years to address these drawbacks. One of them is the work on the extension of an active DSS into a so called decision station that is capable of providing a complete support environment to the decision-maker (Vahidov 2002; Vahidov & Kersten 2003).

Dss research focused on the providing support to individuals or groups rather than separated organizations with different interests and goals. It also largely ignored the issues of supporting decisions associated with the design of and integrating components into a single product. The systems built on the traditional DSS concept, i.e. Simon's (1960) intelligence-design-choice-implementation model, are disconnected from their problem domains.

Inspired by software agent technologies, new frameworks of DSS have been proposed, including active decision support and decision station (Vahidov & Kersten 2003). A decision station (DS) provides active support and also monitors decisions implementation and the changes in the problem environment which may necessitate modifications of the decision. It performs these functions through the use of sensors and effectors.

The difficulty in the design and implementation of active and connected DSSs was due to the lack of connectivity among different information systems in an organization and between these systems and the organization's environment. The ubiquitous network and pervasive computing demand new approaches that will allow an information system to interact with and use various information environments. A local environment consists of systems, databases and other computing resources which have been designed in a way to allow them sharing resources and exchanging information.

Increasingly, important information is not readily available in the local environment. To obtain such information, software agents and other systems must go outside and actively search in other local environments, which are external to them. This introduces the issue of the systems' capability in operating in and interacting with the "foreign" environments. These systems, however, must be connected to both the decision problem's environment and these "foreign" environments in order to operate effectively and leverage the systems' capabilities.

The goal of a situated, connected and active DS is to provide all services necessary for decision-making and implementation. Thanks to the situating characteristics, a DS is capable of:

- sensing what's going on in the problem domains;
- utilizing traditional DSS facilities to inform decisions;
- making and justifying choices; and
- undertaking implementation and monitoring activities.

3 ARCHITECT'S DECISION STATION

The nodes of the supply chain are organizations; they are the members participating in the project. From the information system perspective they represent a network in which we can identify decision stations and their environments. To simplify the discussion, we assume that one DS is associated with one node. The information environment consists of other information systems which the DSS access in order to obtain information and which behaviour they want to affect.

3.1 *Decision station architecture*

We are interested in a DS which can interact with other DSS installed in different organizations. Both the architect's decision station (A-DS) and the cooperating organizations' stations (C-DSS), for example, an engineer, a team specialized in indoor comfort, or a ceramic shingle producer supplying the entire pitched roof, may be small or medium enterprises (SMES). Even if one or more of the organizations are large, we cannot expect every participating organization to use the same ontology. Moreover, both A-DS and C-DSS may need to access organizations, which do not participate in the project, but have potentially useful information. For example, an indoor comfort specialist may need to access information about different products for heated floors.

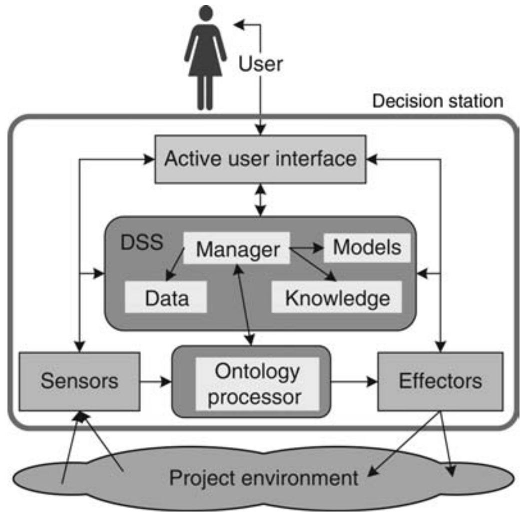

Figure 1. Decision station architecture (adapted from Vahidov & Kersten 2003, p. 288).

The necessary capability for every DS is its ability to "understand" the information that its sensors retrieve from the environment, and also for the effectors to provide input to the selected systems (e.g., web sites) in the environment in the way that these systems can understand. For this purpose a DS needs access to ontology and a processor, which can compare and translate concepts from one ontology to another. Providing DS with ontology also enhances its ability to interact with the user. Another purpose for the introduction of ontology and a processor capable of interpreting documents written with different ontologies is to provide the system with an ability of autonomous search and evaluation of information available on the web. The DS and its key components and functions used in the cooperation with the user and situated in the environment are shown in Figure 1.

3.2 *Interface and dss components*

The user interface needs to be active; it needs to be capable of engaging in and facilitating human-machine dialogues. Such interfaces may incorporate synthetic characters, reside on wearable devices, and have learning capabilities. One of important characteristics of such an interface is its ability to adapt to the user and customize the system in ways that match the user's cognitive abilities and needs.

The core of the DS is the DSS which includes the manager, model base, knowledge base and database.

The manager organizes and controls the functioning of the DSS. Dss requires a knowledge base (including, business rules), that make the system capable of performing certain tasks autonomously (without the user intervention). These and also the model- and data-base are standard components of a dss discussed in literature (e.g., Holsapple & Whinston 1996; Carlsson & Turban 2002; Shim et al. 2002).

3.3 *Sensors and effectors*

Sensors and effectors are key components that situate the DS and differentiate it from traditional standalone DSSs. They are used to interact and affect the environment. The information environment indicated in Figure 1 represents the project environment. It includes all information systems and sources which provide information that may be relevant to the project and its implementation. For example, web sites, including electronic books and magazines containing samples of sustainable solutions; different information related to materials and multilayered solutions; normative references with threshold values that must be respected; software for evaluations/measurements; and sites with information on buildings and constructions, and producers with technical reports and measurements on their own materials/solutions.

We can distinguish two general types of sensors and effectors' capabilities: passive and active. Passive functions must be invoked by other DS components reacting to the user's request or acting independently. Examples of passive capabilities include connecting to external sources, extracting information requested by other DS components and transforming it for the components' use. Sensors also pass information to the environment either by posting it or sending to specific systems (e.g., requests, questions and answers).

Active capabilities include checking the state of the environment and querying and alerting users, adapting and planning.

The DS problem environment could be complex because of the frequent and unexpected changes and the very large number of variables required to describe it. Ds was originally envisioned to financial planning and investment decision problems for which the environment was stock exchange .(Vahidov 2002). Such an environment is semantically simple; it does not include numerous web sites which may use different concepts and terms. These concepts are extended here into heterogeneous environments characterized by the use of multiple ontologies, data bases, and incompatible software and hardware.

4 SITUATING ARCHITECT'S DECISION STATION

To design a sustainable building, choices have to be made about the structure, the building envelope, the internal floors, the plants in the building, and so on. In particular, the thermal behaviour of the building envelope is a key factor for energy saving (Balaras et al. 2005) and all its parts, i.e., the ground floor, the external wall and windows, and the roof, must be appropriately designed.

To illustrate the complexity of the design and the need to use multiple sources we consider the initial design of the envelope. It is known that a layer of insulation material included in the envelope gives a benefit in terms of thermal resistance (Al-Homoud 2005). In addition a ventilation layer included in the envelope contributes to preventing moisture build up (Davidovic et al. 2006). It also reduces the thermal load when the outside temperature is high (Dimoudi et al. 2006). Consequently, a building envelope may consist of: (1) a wall with insulation on the exterior and the vertical ventilation, (2) a flat roof with insulation and ventilation, and (3) the ground floor, which is known as "walls on the ground". This type of the floor includes a layer of insulation and a horizontal ventilation. This may be the type of a solution that fits both the sustainability objectives and the objectives of providing indoor comfort for the building occupants. However, in order to select a concrete solution a number of choices need to be made regarding the materials, calculations of the air flows, thermal resistance and inertia, etc.

4.1 *Accessing and using technical documentation*

We illustrate the need to situate a DSS, that is, the DS feature called situatedness, with examples of accessibility and use of technical documents available on the web[2].

Successful sustainable design requires an integrated approach; sustainable buildings must take many factors into consideration on a "whole-building", integrated basis. Envelope design is a major factor in determining the amount of energy a building will use in its operation. In general, it is necessary to build walls, roofs, and floors of adequate thermal resistance to provide human comfort and energy efficiency. Thermal protection must be provided by appropriate levels of insulation and minimal air leakage. At the same time, preventing moisture build-up within the envelope is essential.

The moisture should not only be permitted from entering the building envelope, it should be allowed to escape as well. For example, water vapour that works its way into a wall cavity should have a way to rise to the top of the wall and escape through an attic vent, just

[2] Based on: *Sustainable Building Technical Manual. Green Building Design, Construction, and Operations*. Produced by Public Technology Inc. US Green Building Council. Sponsored by U.S. Department of Energy. U.S. Environmental Protection Agency (1996), available on the website http://www.wbdg.org/ccb/SUSTDGN/sbt.pdf.

as liquid water that condenses within a cavity should have a way to migrate out through a weep hole at the bottom. This ventilation should not be confused with ventilation of the occupied spaces. Cold roof strategies that use air spaces between the exterior weather barrier and the substrate beyond employ natural ventilation to circulate the outside air. They minimize the heat transfer through the roofing system and eliminate an unnecessary heat gain in the summer.

4.2 *Interacting with the producers' portals*

Before the supply chain is set up for the particular given project, it is necessary to decide on the materials and components that would be used in the construction. This requires verification that the most recent available information is obtained, as in the following example based on producers' portals [3].

Decisions about insulation are among the most important to make in relation to the environmental impact of buildings. Utilising the best quality insulation systems allow us to provide the most energy efficient building envelopes. A building envelope is the combination of the foundation, wall, and roof assemblies all working together to provide a comfortable and safe environment in a building. However, modern constructions using higher levels of thermal insulation require increased levels of ventilation within the building fabric to prevent the build-up of moisture and condensation.

The insulated ventilated roofing and walling are the utmost living comfort, since control over heat dispersion and disposal of vapour during the winter, and reduce incoming heat flows during the summer. Moreover, with the increasing awareness of hazardous subsoil gases such as radon and methane, the need for under-floor ventilation has become even more apparent.

5 DECISION STATION NETWORK

The organizations with which the architect collaborates in a given project form a network. This network is project-specific *ad hoc* supply chain because some of its nodes appear only in one project but not in another.

5.1 *Network overview*

An example of the network set up by the architect is illustrated in Figure 2. From the perspective of the architect, the network has elements of a hierarchy with the architect's station (A-DS) positioned at the top-level. At the second level are those members of the supply

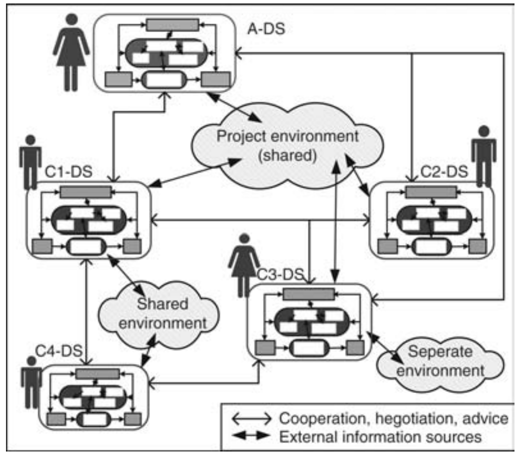

Figure 2. A network of decision stations.

chain who communicate directly with the architect. For example, a wall designer (C1-DS) is at the second level. This wall designer may interact both with the architect and a producer of ventilated facades (C4-DS). If this producer does not interact directly with the architect, then he is a the third level.

The supply chain and the information network associated with it are established for a given project. They are, however, not stable and we cannot assume that they remain unchanged during the life of the project. The configuration may need to be modified if the architect or the contractors realize the necessity to engage other experts or producers (in Section 6.2 an example of two producers of ventilated facades is given).

There are two more nodes in the network depicted in Figure 2; they are at the second level and represent, for example, a roof designer (C2-DS) and a producer of a specific solution for the ground floor (C3-DS).

All information about the architectural project and related activities, both directly and indirectly, comprise the shared project environment. Separating the environment from the architects DS (A-DS) allows other members to collaborate with and without the architect's involvement.

One of the characteristics of the *ad hoc* supply chains is that they pull together organizations that belong to other supply chains (which may be highly specialized) and collaborate with other organizations outside of any chain (e.g., research institutes, laboratories and technical associations). The implication is that some of the members access information coming from two or more information environments. This is illustrated in Figure 2; the wall designer (C1-DS), and the ventilated wall producer (C4-DS) share an environment between them. This environment may allow the members accessing producers of new materials used for ventilated walls. An example of an environment

[3] Based on: http://www.foam-tech.com/theory/theory.htm; http://www.bbs-ltd.com/ventilation.htm; http://www.pica.it/news01_en.asp

that is used by one member (C3-DS) but not shared with others is also shown in Figure 2.

5.2 *Example*

We illustrate the operation of the establishment of the supply chain and the associated information network with the following scenario. This network is shown in Figure 2.

Architect A proposes a particular type of ventilating the building, which, because of the unusual design and environment, cannot be one of the typical ventilating solutions. She consults the internal and external databases and websites and selects one ventilating approach combined with a layer of insulation material, as a means of assuring indoor comfort along all seasons. Consequently, she selects the initial contractors with whom she will collaborate in the project. This selection is based on the competencies and abilities required for this project. Then, after sketching a draft with the main features of the project and the required performances of the building she selects three contractors who will be involved in the building: C1 is responsible for the external walls, C2 for the flat roof, and C3 for the ground floor.

A presents the draft to the three contractors. Based on the architect's draft, contractor C1 decides that he needs a ventilated wall producer. He suggests producer C4, who will be responsible for the technical design of the specific system chosen for the facade as well as the future mounting operation. After the interaction between the two, on the basis of suggestions by the ventilated wall producer, C1 proposes an external wall in the project based on a multilayered solution, i.e., (from inside toward outside), 2.5 cm internal plaster layer, 24 cm layer of airbricks, 10 cm thick layer of polystyrene as thermal-acoustic insulation, 8 cm of a ventilated cavity, and 1 cm of metal external protection.

Contractor C2 studies the problem and proposes a flat roof in the project based on a multilayered solution, e.g., 8 cm layer of stone wool as thermal-acoustic insulation, 6 cm ventilated cavity made by PVC supports, 5 cm layer of reinforced concrete, and a waterproof layer. C2 adds that, depending on the roof's additional usage, other layers may need to be added.

Contractor C3 is responsible for the ground floor; she proposes the following multilayered solution: a 30 cm layer of recycled PVC igloo elements, which create the ventilated cavity, a 12 cm layer of reinforced concrete, a 6 cm layer of stone wool as thermal-acoustic insulation, a sheet of aluminum as vapour barrier, a 5 cm layer of light concrete, and finally mortar and flooring.

Contractors CI, C2, and C3 discuss their proposals with A including the calculations of the solutions' thermal-acoustic performance. They also present the proposed components' adherence to the laws and regulations in place.

Architect A considers the proposals made by C2, and C3; who somewhat unexpectedly for A, propose using stone wool for insulation. During the discussions, which could be conducted online, C2 and C3 access technical documentation on the producers' portals and proprietary technical databases. They provide A with the relevant documentation which convinces her and she now wants to use stone wool also for the wall insulation rather than polystyrene, which C1 proposed.

Architect A informs C1 about her discussion with contractors C2 and C3, and asks him to consider using stone wool, or another thermal-acoustic insulation material more environmentally friendly than polystyrene. She also suggests that C1 talks with C2 and/or C3 who have experience in these matters. A requests that C1 suggests a ventilated wall with the outer face made of material other than metal.

Consequently, C1 interacts with C2 and C3 to check the use of stone wool in his solution. He also contacts producers of external protection of ventilated walls in materials different from metal (e.g., stone and ceramic). From the interaction between C1 and C2 and C3, but also accessing technical documentation and producers' portals, C1 derives the necessary information for changing the insulation material in his solution. By the contact with producers and again accessing technical documentation and producers' portals, C1 makes a choice for the external protection of the walls, as for example ceramic tiles. Then, he checks the new solution with the ventilated wall producer and finally he proposes the new complete solution to A.

5.3 *Control*

There are five nodes in the exemplary information network; each is represented by one decision station. Because of the nature of the underlying supply chain, both hierarchical and horizontal connections are necessary between some of the stations.

The architect's decision station (A-DS) is at the top level because it represents the architect who is the project owner and the top-level coordinator. There are three contractors with their decision stations C-DS, at the second level; they directly collaborate with the architect, and one contractor with C-DS at the third level.

The five stations are engaged in cooperative activities, negotiations, advice and so on. During this initial phase of the design development, the architect plays the major decision making role, acting with a top-down approach. One result of this approach is the selection of the contractors, that is, the specification of the network's second-level membership. At this stage, the architect also allocates tasks to each member. Some members, in order to achieve the goals, may decide to extend the network with third-level members. One such third-level member (C4) is indicated in Figure 2.

After the network has been set up, the interactions between members begin. They are based of the common goal, and they are not only required by the architect but also suggested by the members of the network themselves. Moreover, a feedback process begins, that is the bottom-up process is activated. This system of relations has both horizontal and vertical bi-directional flows. These relations increase the flexibility and adaptability of the network in that they allow for: (1) the inclusion of more members in the network at any level; and (2) the evolution and changes of the design.

During the central phase of the design activity, it is likely to have the members in the second and lower-levels proposing their suggestion as the most important for the goal to pursue, thus a competition arises between members, and consequently design solutions. With the design solutions suggested (supplied by the members in the network), the architect has the task to relate the one to the other, beyond the single suggestions, to create a unique solution for the whole design. This final solution is not usually defined after the first attempt, but derives from an iterative process typical of the design activity. In the iteration, the possible solution goes back and forth from the architect to the other members of the network, encouraging a collaborative process helping the definition of the final solution.

6 UNDERSTANDING AND COMMUNICATING

We have mentioned that the members of ad hoc supply chains may use heterogeneous and incompatible ICT solutions. They may also use different terminology. Therefore, there is a need for tools that make communication more effective by facilitate shared understanding of the requirements, designs, and their implications.

6.1 *Ontology*

Effective communication between a DS and its users can be made easier and more effective if the system has access to ontology. An example of such ontology for the building design is given in Figure 3. This example corresponds to the scenario discussed in Sections 4 and 5.

Ontology is used to organize the concepts and the relationships between them. It provides detailed specification of the relationships in a domain.

Ontology may be a component of a DS or it may be external to the system and part of the problem environment. Location outside of the DS allows other systems

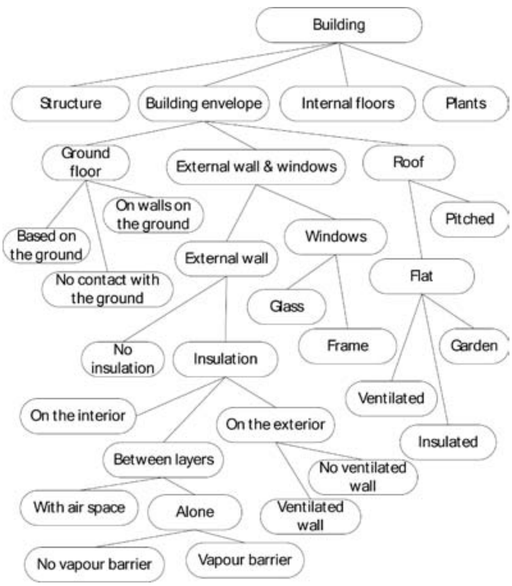

Figure 3. Ontology of a (sustainable) building envelope (ground floor + external wall & windows + roof).

to use it. In either case, the DS requires an ontology processor which allows it to interpret the requests made by the user and other systems, to interpret information retrieved by its sensors and to prepare output in the ways easy to comprehend by the user. Ontology also helps the DS to give explanation and justification of the choices and assessment made by the system because it provides contextual grounding for the terms used.

6.2 *Use of ontologies for communication*

In semantically more complex environments, it would be unreasonable to assume that every information source and every collaborating station use the same classification system and common vocabulary; that is different servers and stations may use different ontologies.

Every person involved in a project has (should have) an understanding of terms that other project participants use. This is due to the common technical knowledge and the participants' expertise and earlier interactions with people from related domains. The use of ICT, however, requires that either all systems use exactly the same terminology or that there are solutions that can translate statements made within the domain of one supply chain member into statements used by another member. The first solution is impractical as it would require everyone to "speak the same language". The second solution involves the construction of ontologies for each domain and equipping the participating DSs with ontology processors. Because,

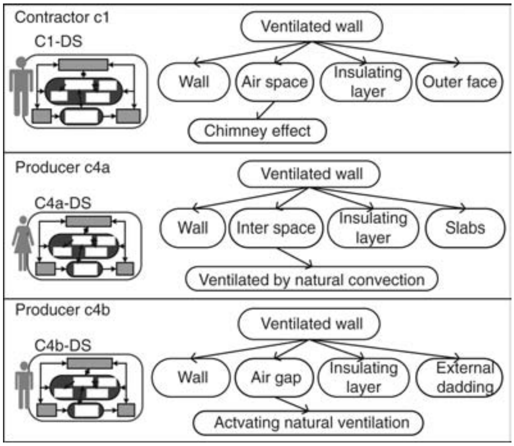

Figure 4. Ontologies of a ventilated wall by a consultant architect and two different producers.

as we mentioned above, such processors are useful in a DS interaction with its users, the second solution is preferable.

To illustrate this we continue with our scenario. Consider that contractor C1 is responsible for the external walls. This contractor contacted two producers[4] (C4a, C4b) and asked to propose solutions for a ventilated wall. He recommended an accurate calculation of the "airspace" in the wall so to obtain appropriate ventilation through the "chimney effect".

The contractor received one draft in which the wall has an "interspace" and is "ventilated by natural convection". The second draft proposed an "air gap" with a specific dimension sufficient for "activating natural ventilation". The contractor knows that all these terms have the same meaning concerning the function. However, if this contractor's decision station C1-DS has to make a decision, then it would have to reject the two proposals sent by C4a-DS and C4b-DS because they use a different terminology than C1-DS. This situation is illustrated in Figure 4.

The use of different terms requires that the DSs that participate in the supply chain can access different ontologies and compare the terms.

7 DISCUSSION

Recent developments in individual decision support include the provision of active and responsive support functions, and the situating of DSSs in their environments. Building on these developments we propose a network of collaborating DSs that is established when required. This type of a network is the informational equivalent of an *ad hoc* established supply chains.

Architects and their collaborators comprise a supply chain with the membership depending on the project they are involved in. The projects they are involved in are increasingly complex and the supply chain membership may change during the project's life-span. Furthermore, the members typically belong to several other supply chains and other associations. All these factors need to be taken into account when systems supporting individual members and the information network for the whole chain are designed. In this paper such a design is proposed and illustrated.

There have been several prototypes of DSs in financial domain. They have shown their usefulness and the design of production-type systems is now considered. In the financial like in many other domains, an introduction of new information systems needs to be carefully planned. It involves the development of small-scale prototypes and their extensive testing. The first step in this work will be the adaptation of the existing DS to architectural domain and the construction of the networked collaborating DSs.

Following the initial prototyping development phase, we move to the architectural context in academia and set up simulation experiments with students representing supply chain members. This should give us insights into the flexibility and robustness of the proposed solutions. Another purpose for this type of testing is the verification of the use and processing of ontologies; we expect that students, being inexperienced will be using different terms for the same concepts.

This work presents research which is evolving and moving from the drafting stage to design and then development and implementation. The purpose is to provide effective and efficient decision support to architects and other organizations involved in designing. Our goal is to provide tools that will aid decision-makers in designing and constructing sustainable buildings. We view decision-support being essential because of the demands placed by the sustainability requirements and the associated with it vagueness and uncertainty ...(Robinson 2004). The reduction of an information overload that we face is helpful but not sufficient. It needs be augmented with the reduction of the cognitive demands. They are imposed by the complex, dynamic and evolving projects and the need to learn about an increasing number of new solutions. They are also imposed by the difficulties in putting together different components, and the necessity of addressing environmental and social issues which became increasingly important. There are no panaceas or tools that help addressing all these demands, but information systems which are

[4] Based on: http://www.ripabianca.it/pareti ventilate/Din Std.asp?COD_PAG=178&grp_col=3&sx=TOP&tp=SX&bg=000000; http://www.estel-company.com/razdel/51/

media rich, intelligent and capable of communicating with each other and with people are necessary.

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Robust process-based multi-project scheduling for construction projects in Vietnam

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ABSTRACT: The resource moving time among the projects is assumed to be negligible in the current heuristic methods which are used to generate resource-constrained multi-project scheduling (RCMPS). This assumption is unsuitable in construction industry since construction projects are usually far away from other projects and from the head office. Specially, in the Vietnam situation with an inconvenient transport system, allocating a resource from one project to another is greatly constrained, and it always involves extra costs and time loss. Furthermore, the assumption of heuristic methods is based on a static determined environment during project execution phase. The construction projects are often deployed in an open execution environment, the activity durations must be considered as uncertain. The main purposes of this paper are: firstly, to include the resource moving time among projects into the resource-constrained multi-project scheduling (RCMPS-RMT) process; secondly, to incorporate the heuristic methods with the scheduling philosophy of the Critical Chain Project Management for strengthening and stabilizing the scheduling against the unexpected problems during the construction phase.

1 INTRODUCTION

Construction contractors usually deploy simultaneously multiple projects under limited resources (e.g., labors and machines) condition. To perform multiple projects, a construction contractor can access two sources of resources: *internal resources*, which are under the contractor ownership and *external resources* which can be obtained from the open market. The common objective is to create the most efficient schedule possible to maximize the usage of the contractor's internal resources and just use the market to balance the contractor's operation (Shi & Halpin 2003).

Because the project duration is one of the main factors of competiveness on the difficult construction market, the most important part of a construction project scheduling is the assignment of resources and the harmonization of their work to minimize the project duration. These problems can reputedly be solved as the well-known problem in the operation research: Resource-Constrained Multi-Project Scheduling (RCMPS) (Kurtulus & Davis 1982).

The scheduling of multiple projects under resource constraints demands extreme difficult computation. In addition to the precedence constraints (technical relationship) between activities within individual projects, there are precedence constraints of the activities among multiple projects due to the sharing of the scarce resources sharing. Therefore, the RCMPS is a hard nonlinear programming problem. There are two fundamental approaches to the resource-constrained project scheduling process: optimization models and heuristics. Optimization approaches seek the best solutions; however, they are far more limited in resolving the large and confusing projects and often require unreasonable computation time (Sprecher et al. 1998). Hence, heuristics are often applied to generate near-optimal schedules for large and highly constrained projects.

In traditional heuristic methods, most researches have mainly assumed that the resource moving time (RMT) from one activity/project to another is negligible (Hans et al. 2007). When multiple projects are deployed in different places and far from each other, this assumption has many shortcomings for properly modeling the real-world constraints. Specifically in the Vietnam situation with an inconvenient transportation system, the travel speeds are low and there are unforeseen delays due to traffic density and quality limitations. Allocating a resource from one project to another is greatly constrained, and it always involves extra costs and time losses. Hence, the resource moving time noticeably influences the multi-project duration in multi-project scheduling processes.

Besides, the assumption of heuristic methods is based on a static determined execution environment.

Table 1. Most widely used priority rules in heuristic methods.

Priority Rule (Primary)	Commentary	Formula	Tie-breaker (Secondary)
SOF	Shortest Operation First	$\text{Min}d_{ij}$, where d_{ij} is the duration of the ith activity in jth project	FCFS
MINSLK	Minimum Slack First	MinSLK_{ij}, where $SLK_{ij} = LST_{ij} - \text{Max}(EST_{ij})$ and terms are defined in standard CPM	FCFS
SASP	Shortest Activity Shortest Project	MinF_{ij}, where $F_{ij} = CP_i + d_{ij}$ where CP_{ij} is the duration of the critical path of the project jth.	FCFS
LALP	Longest Activity Longest Project	MaxF_{ij}, where F_{ij} is determined in SASP	GRES
MOF	Maximum Operation First	$\text{Max}d_{ij}$, d_{ij} is defined in SOF	GRES
MAXSLK	Maximum Slack First	MaxSLK_{ij}, SLK_{ij} is defined in MINSLK	GRES
MINTWK	Minimum Total Work Content	MinGij	FCFS
MAXTWK	Maximum Total Work Content	MaxG_{ij}, G_{ij} is defined in MINTWK	FCFS
FCFS	First Come First Served	MinES_{ij}, where ES_{ij} is early start time of the ith activity from the jth project.	Random

$\text{GRES} = \text{Max}(\sum_{k=1}^{K} r_{ijk})$, r_{ijk} denotes the resource k is required by activity i of project j.

$G_{ij} = \sum_{k=1}^{K} \sum_{j \in AS_i} d_{ij} r_{ijk} + d_{ij} \sum_{k=1}^{K} r_{ijk}$; K is the number of renewable resource types $k = 1, \ldots, K$; d_{ij} is the duration of the ith activity in the jth project; r_{ijk} is the resource k required by activity i of project j; AS_i is the set of the activities already scheduled of project i.

Construction projects are often deployed in an open execution environment, during the execution phase of construction projects, the initial scheduling always has to be adapted to the reality state due to the dynamic and incomplete data. Hence, project activities must be subject to considerable uncertainty, which may lead to numerous schedule disruptions.

In respect to project scheduling problems under an uncertain environment, the Critical Chain Project Management (CCPM) (Goldratt 1997) method has emerged as an effective method in scheduling and controlling project management. The scheduling philosophy of CCPM approach is the emphasis on the equal importance of the interdependencies that are associated with activities and resources. To manifest this point of view, this method suggests a Critical Chain which is defined as the longest sequence of activities and resource dependent activities. The safety time in the critical chain is removed from the individual activities and put into the buffers. The project scheduling will then be guarded against uncertainty by these provided buffers.

Unfortunately, CCPM is not explicitly applicable to RCMPS process. With respect to RCMPS, CCPM staggers projects around the drum resource (the most loaded resource across projects). Additionally, CCPM has just focused on one type of the resource constraints (humans). For construction projects this concept is limited and unrealistic, since the achievement of construction activities often requires the consistent cooperation of many resource types (machine, labor and materials).

The main drawback of existing scheduling methods is the fact that they fail to solve complex practical problems effectively and do not allow for real world conditions and construction constraints. This paper presents a new solution that integrates the advantages of heuristics method with the scheduling philosophy of CCPM to overcome the limitations of the existing methods. The objective of this solution is to construct a robust multi-project scheduling which can be applied for Vietnamese construction contractors maximizing the utilization of internal resources (labor, machines and equipment) for the implementation of the bided projects.

2 IMPROVEMENT OF THE HEURISTIC-PRIORITY RULES METHOD

2.1 *Heuristic-priority rules method*

Heuristics based on priority rule have been one of the most important solution techniques for resource-constrained multi-project scheduling with renewable resources. Since they are not only easy to understand and to implement but also fast in terms of computational effort, and obtain acceptable results even for large sized projects. Furthermore, they are often contained in commercial software packages for project scheduling. The heuristic-priority rules method is made up of two components, a schedule generation scheme and a priority rule. In the scheduling scheme, two different schemes can be distinguished: serial scheme and parallel scheme (Kolisch 1996).

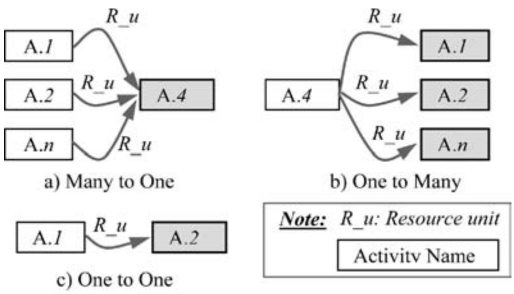


Figure 1. Resource Transfer Models.

Serial scheme select an order of activities to be scheduled prior to considering the resource constraints to be evaluated. The parallel scheme reorder the set of activities to be scheduled as the resource constraints are evaluated. Both generate a feasible schedule by extending a partial schedule (i.e., a schedule where only a subset of the activities has been assigned a finish time) in a stage-wise (split between various stages) fashion. The priority rules are presented in Table 1 will estimate and rank the eligible activities at the current time point with the goal of obtaining the shortest multi-project durations.

2.2 *Improvement of the heuristic-priority rules method*

2.2.1 *Resource transfer time among projects*

In the resource-constrained scheduling process, if there are enough required resources to schedule an activity, the activity is scheduled at its earliest possible time according to its technical relations with precedence activities. However, if there are not enough required resources for scheduling, this activity should be delayed until it acquires enough available resources. After it is delayed day by day, all or some amount of resources that caused the delay of the activity should have been released from some other activities' completion. At this time, the required resources are available throughout its whole duration. Like this, one or more resource links are created between scheduling activity and completed activities and the commenced date of the scheduling activity will be *the delay time* plus *the transfer time* to move the resource from the finished activity to the scheduling activity.

Generally, there are three models of the resource transfer among activities: a) the resources are transferred from many activities to one activity; b) the resources are transferred from one activity to many activities; c) the resources are transferred from one activity to one activity as presented in Figure 1. In the multi-project scheduling process, at a point of time there may be many resource types which will be released from different finished activities. Thus, there is a normal logicality that the scheduling activities will first take the resources from the nearest activities. Then, there are not enough required resources; it will continuously consider the resources from further activities. To take this logical analysis to the scheduling process, this paper proposes a new priority rule: *Minimum Resource Moving Time* (MinRMT), which ranks the finished activities follow an order to support the released resources to the scheduling activity. This priority rule is referred to the well-known algorithm Dijkstra's algorithm (Dijkstra 1959).

2.2.2 *Resource flow network*

In the contractor's construction operation, the resource flow network (resource allocation plan) is one of the basements of the internal management system. To achieve the effective performance and consistent working cooperation in the project execution, the resource flow network (RFN) will be announced to every responsible agent such as site managers, workers department managers and machinery pool managers etc. Therefore a RFN is necessary to identify and to depict the amount of resources that are transported from the end of one activity to the beginning of another activity, from this project to the other projects.

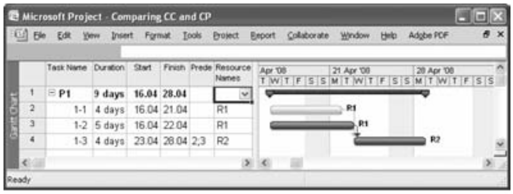
The resource flow network is generated based on the resource links that are created among activities in the multi-project scheduling process (see Fig.1 and Fig. 10). This network therefore will be consistently associated with the multi-project scheduling and the managers can easily assess the effects of the resource contention on various projects and see the interdependencies among projects and the causal relationships influencing various projects.

Additionally, this network is also extremely useful in the case that some special activities in emergency situations need to immediately concentrate the resources to accomplish before the required date. Based on the resource information from the resource flow network, the project managers can make the resolving decisions more quickly. Besides, in practice the construction contractor has also to face with a continuing demand to execute new bided projects. Therefore, several times during the course of a typical business day, the central manager may need to re-control the resource availability to bid new projects. This problem also needs the information from the resource flow network.

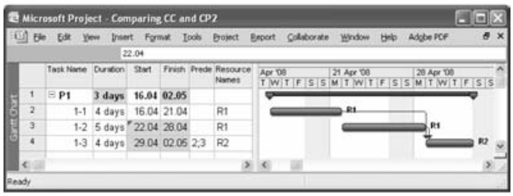
3 THE SCHEDULING PHILOSOPHY IN CRITICAL CHAIN PROJECT MANAGEMENT

3.1 *The concept of a Critical Chain*

One of the fundamental advantages of the Critical chain project management (CCPM) is that it explicitly recognizes the interaction between activity durations, precedence relations, resource requirements



(a)



(b)

Figure 2. Critical Chain and Critical Path.

and resource availabilities in the determination of the project scheduling. This interaction is presented by an activity sequence-*Critical Chain* (Goldratt 1997). The Critical Chain is the longest sequence of activity – and resource-dependent activities in a project. This concept approaches the management that differs in important respects from the traditional critical path method (CPM). The critical path is also a longest chain of activities in a project scheduling. However, the CPM considers only precedence relationships between activities, while ignoring resource conflicts.

To illustrate the difference between the CCPM and CPM, Figure 2(a) and (b) show a simple example that consists of three activities are respectively scheduled according to CPM and CCPM under two single-unit available resources R1 and R2.

Figure 2(a) presents the critical path-based project schedule that consists of activities 1-2 and 1-3. Because the capacity of resource R1 is limited to one available unit, so the critical path in Figure 2(a) is unrealistic since this critical path has ignored the competition of the resource R1 between activity 1-1 and 1-2. Contrastingly, with the critical chain calculation, the resource- and precedence – dependence are included so the critical chain is 1-1, 1-2 and 1-3 which is presented in Figure 2(b). Obviously, the critical chain depicts the constraints of project scheduling under the constrained resource conditions more explicitly than the critical path (CPM).

3.2 *The buffers and buffer management*

3.2.1 *The purpose of buffers*

In the traditional method, the contingency buffer in construction planning often allocates certain time in individual activities to absorb a certain delay on the execution of the individual activity.

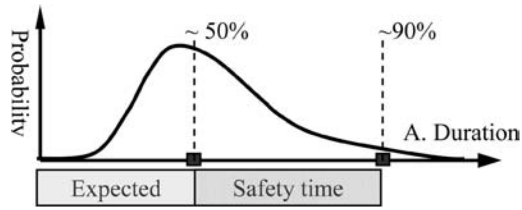
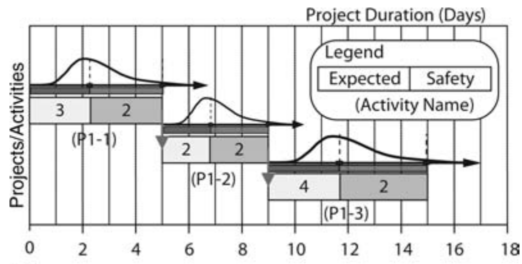
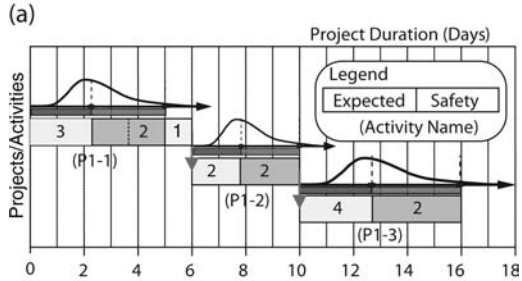


Figure 3. Assumed distribution of activity duration and completion probability.



(a)



(b)

Figure 4. The traditional buffer in project scheduling.

Figure 3 indicates the buffer calculation as in the traditional method. The expected activity duration value is the duration that in the case the activity is supported with the required resources to perform during the execution phase and that there are no unexpected events arising. Hence, this value is just 50% likelihood of completing activity on time. Against the uncertain factors (weather conditions, the equipment is broken, the workforces are absent etc.), the planner often adds significant safety time. Normally, this value is increased to 90% likelihood to complete the activity on time.

In fact the position of the buffer that is embedded in the activity level does not provide any prevention mechanism of possible schedule disruption; rather it just gives time to the project manager to recover a disruption. To make this state more clear, let us consider a simple example as show in Figure 4.

As depicted in Figure 4(a), a simple project contains a three activities sequence. Each activity contains the expected time and the safety time inside. Actually, the safety time is hidden in the activity duration, and

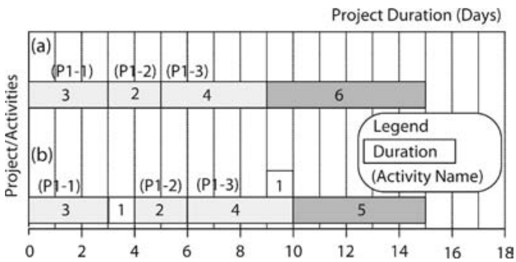


Figure 5. Buffer in CCPM.

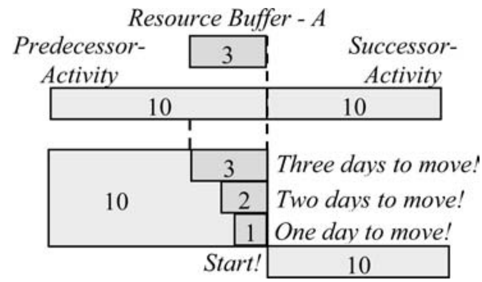


Figure 6. Explaining Resource Buffer [modified from Zultner (2003)].

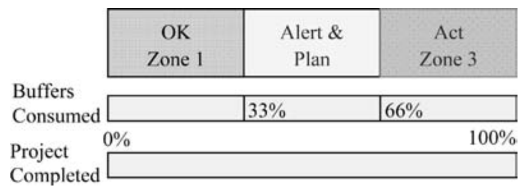


Figure 7. Buffer management in the project execution phase.

the project manager just sees the total activity duration, such as with the activity (P1-1) is 5 days. What happens in the execution phase? Assumed that, activity (P1-1) uses 1 day of safety time due to an unforeseen problem, in fact the project manager really does not care about it because this value is still within the total activity duration (4 days $<$ 5 days). However, this is no longer the case if the activity (P1-1) is extended to two days more, this will immediately extend the whole project duration to one day as shown in Figure 4(b). Obviously, this is an accomplished fact. This case may be also similar to the activity (P1-2) and the result is predictable, because the late activity finishes will accumulate to the delay of project completion. As a result, the intended buffer is not effectively used in traditional way. To overcome these problems, CCPM argues that the safety time should be eliminated from individual activity duration estimates and aggregated in the form of buffers at crucial locations in the baseline schedule as shown in Figure 5(a).

As this way, the consumption of the intended buffers will be explicit. For instance, as presented in Figure 5(b), in the case activity (P1-1) is extended for one day, immediately the buffer will be shorter to one day, so the project manager will be alerted and has to prepare a resolving method if the activity (P1-1) is potentially extended more.

There are three types of buffers that are presented in CCPM: *Project Buffer, Feeding Buffers and Resource Buffers.* The project buffer is used to protect the critical chain and is placed at the end position of the critical chain. Feeding buffers are inserted at the last activity on non-critical chains (feeding path) to against the delays that influence the critical chain. Resource buffers will not contribute any amount of time to the project duration, just in the form of an advance warning system. For example as presented in Figure 6, the resource buffer of the resource A is assigned to three days. Then it is started after the 7 working days, a notice is implemented, "Three days to move", "Two days to move", "One day to move" and finally the resource A moves to the required activity when the current activity finishes.

In order to determine the buffer sizes, there are two generally adopted buffer sizing methods included: Cut and Paste method (C&PM) (Goldratt 1997) and the Root Square Error method (RSEM) (Newbold 1998). The sizing rule for setting project buffers and feeding buffers in the C&PM is basically to cut 50% of work times for all activities.

Using the RSEM to compute the project buffer and feeding buffer sizes, the safety time of each activity is needed. This value is often estimated by schedulers. And the buffer size is calculated as follows:

$$\text{Buffer size} = 2\sigma = \text{SQRT}\,(U_1^2 + U_2^2 + \ldots + U_n^2) \quad (1)$$

Whereas, n is the number of activities in the critical or feeding chains, and U is the safety time of the individual activity.

3.2.2 *The buffer management*

Buffer management is the process of managing variability or uncertainty to improve throughput. As activities take longer than the schedule anticipated, buffers are consumed. A buffer can be divided into three time zones. Each time zone requires its own set of managerial actions. No interference is needed as long as the buffer consumption is restricted to the first ("OK") zone, the farthest from the deadline. In the second zone ("Alert & Plan"), the management analyzes the problem and prepares the recovery plan. In the third zone ("Act"), the management is directly involved in implementing a recovery plan (Fig. 7).

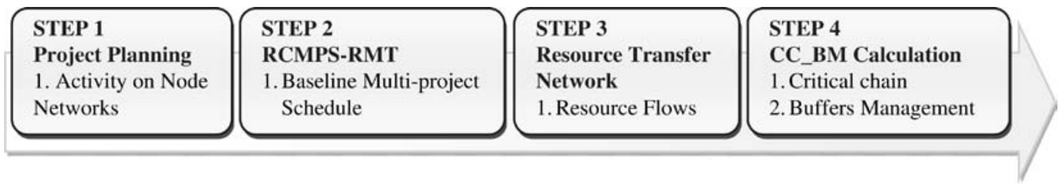


Figure 8. ROMPS and operating range.

4 ROBUST MULTI-PROJECT SCHEDULING (ROMPS)

4.1 *ROMPS-Integrating the improved heuristic method and scheduling philosophy of CCPM*

This paper suggests a new procedure named RObust Multi-Project Scheduling (ROMPS) which is the foundation for project planning and controlling processes of construction projects in Vietnam. Generally, ROMPS is fundamentally represented by two stages. Firstly, ROMPS applies the improved heuristic-priority rules to find a baseline multi-project schedule which satisfies the business objective of the contractor (such as minimum multi-project duration under resource constraints and resource transfer time). Thereafter, the critical chain concept and buffers insertion and buffer management will be applied to immunize the baseline schedule against unforeseen events and to control the project status during the construction phase.

In detail, ROMPS is divided into four main sequence processes as shown in Figure 8. The objective of step 1- *Project planning* is to initialize single project data. These project data includes activity durations which are separated into expected and safety time, activity precedence relationships, activity resource requirements, and resource types. Thereafter, an activity on node (AON) network is often used to represent this project data.

The central part of ROMPS is a new algorithm in step 2: *Resource constrained Multi-Project Scheduling and Resource moving time (RCMPS-RMT)*. This algorithm stems from the improvement of the heuristic-priority rules method as mentioned in the section 2. The objective of step 2 is to establish a feasible baseline scheduling which meets the constraints (resources and precedence constraints) and a minimum multi-project duration in a static execution environment. Note that, the activity duration at this phase is estimated without safety time. This amount of time will be calculated and gathered into the buffers in the next processes.

The baseline scheduling from step 2 is the premise to construct a robust scheduling in step 4. Step 3, the resource flow network that is based on the scheduling results of step 2, is used to depict the amount of resources transported from one activity to another activity due to the resource constraints. In step 4, the critical chain and the buffers in the CCPM methodology are determined and inserted. The buffers will be used to control the execution of the projects through the consumption of buffers during the execution phase. This schedule will be the basement to control the project status.

Table 2. The available resource amount.

Resource Name	RA	RB	RC
Availability	5	4	3

4.2 *Numerical illustration using ROMPS*

To demonstrate the proposed scheduling procedure, an example network consisting of two small projects with a total of eleven actual activities (activity that contains duration and required resources) is used to depict the ROMPS- based scheduling processes.

Figure 9 presents the detailed data of the example through an activity on node network. Practically, this detailed data has been often achieved through a project planning process which is presented in step 1 of ROMPS. The time to move the resources from project 1 to project 2 are assumed is one day. The maximum available resource amount is presented in Table 2.

The available resource amounts are enough to schedule individual projects according to the unconstrained resource conditions. The resource conflictions among projects occur when the individual projects are scheduled simultaneously as depicted in Figure 10. As we can see in the Figure 10(a) the overload of resources RA, RB and RC concentrate on the beginning phase of the two-project network. To solve these problems, step 2 RCMPS-RMT is applied to minimize project make-spans under the resource constrained and resource transfer time.

In this step, the activity duration is considered with the expected duration (without safety time). To schedule multi-project in this case, the heuristic parallel method and the priority rule SOF (Shortest Operation First) are applied. The scheduling results from step 2 and step 3 are presented in Table 3 and Figure 11

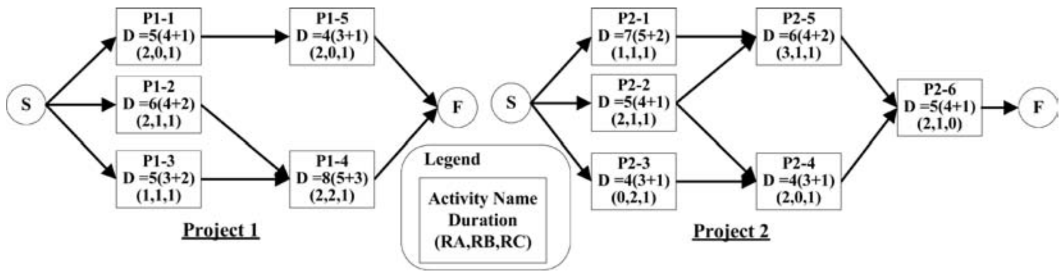


Figure 9. Example of two-project network (Activity-On-Node).

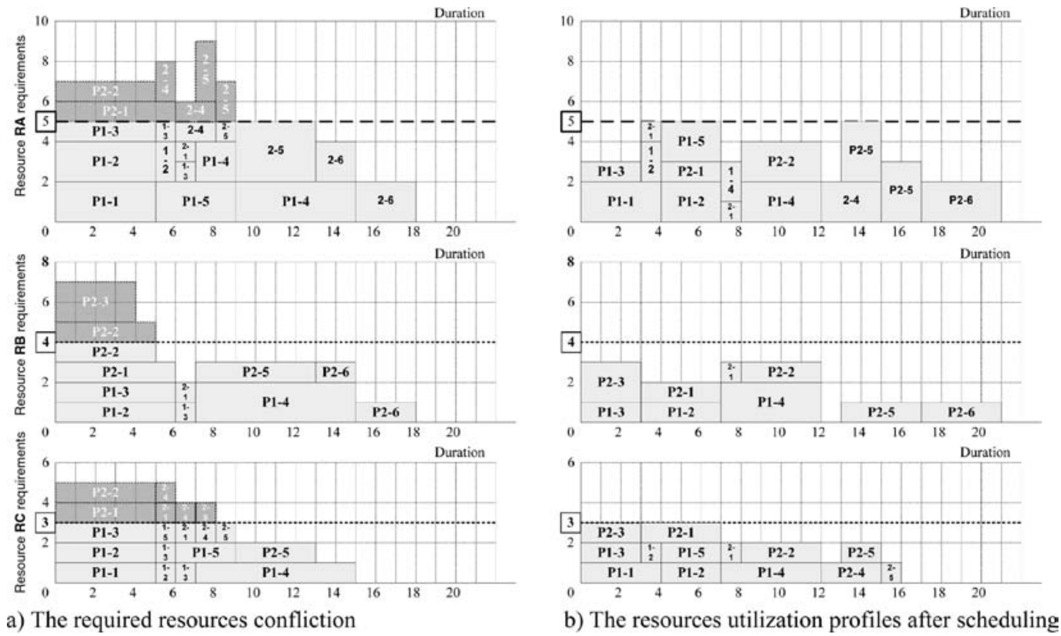


Figure 10. Resource conflict when scheduling simultaneously.

Table 3. The scheduling result according to RCMPS-RMT.

P	Activity	D-E	S	F	A-P	R-P
	1–1	4	0	4	–	–
	1–2	4	3	7	–	1–3
P1	**1–3**	3	0	3	–	–
	1–4	5	7	12	1–2;1–3	1–2
	1–5	3	4	7	1–1	1–1
	2–1	5	3	8	–	2–3
	2–2	4	8	12	–	2–3;1–5
P2	**2–3**	3	0	3	–	–
	2–4	3	12	15	2–2;2–3	2–2
	2–5	4	13	17	2–1;2–2	2–1;1–4
	2–6	4	17	21	2–4;2–5	2–5

Whereas: A-P: Activity Predecessor; R-P: Resource-Predecessor; D-E: Expected Duration.

respectively. The resources utilization profile is represented in Figure 10(b). As depicted in Figure 10(b), all of the required resources after scheduling process are within the available amount. The resource transfer time is also included into the scheduling process. For example as shown in the Table 3, activity P2-2 has a resource predecessor - activity P1-5 and the commenced date of activity P2-2 is delayed one day since the movement of the resources from activity P1-5 to P2-2. Based on the resource predecessors in Table 3, a resource flow network is created as in Figure 11.

To identify the critical chain in each project, the forward pass is applied to find the longest chain of activities and resource-activities in each project. In project 1: Critical chain is a sequence of activities 1-3, 1-2 and 1-4. With the project 2: Critical chain is a sequence of activities 2-3, 2-1, 2-5 and 2-6. Those

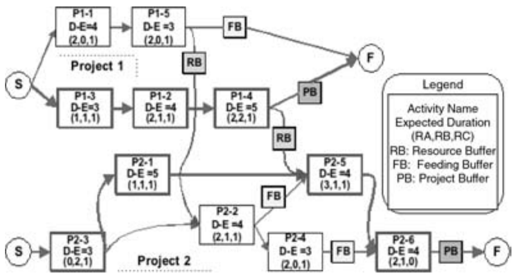


Figure 11. Critical chain and buffer insertion.

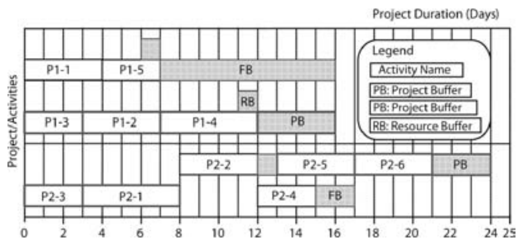


Figure 12. Buffer insertions.

critical chains are presented in Figure 11 with bold boundary and bold arc connections. The next process is to calculate the buffer sizes and insert them in the project schedule. This paper will apply the RSEM method (Newbold 1998) to calculate the buffer sizes. Because in construction industry, the activity duration is often estimated based on the unit productivity rates of resources (Hendrickson and Au 2000) and then the safety time is added to this value.

Therefore the C&PM method (Goldratt 1998) is not suitable to construction project scheduling. Based on equation (1) in section 3, the project buffer of project 1 is 4 days and the project buffer of project 2 is 3 days. These buffers are inserted into the project critical chains as depicted in Figure 11 and Figure 12.

The feeding buffers are placed between any non-critical chain activity and the critical chain activity. Because the non-critical activity may have the activity floats, the two following cases may be considered in this process:

Feeding buffer size larger than Activity Float: In this case, the project duration will be extended by an amount of time that is equal to the differential time between feeding buffer and activity float size. Corresponding with this extension, the other critical chains from other projects which have dependencies with the current chain might be also extended by the same amount of time.

Feeding buffer size less than or equal to Activity Float: If the feeding buffer size is less than or equal to the activity float, the addition of a buffer will not add any protection to the schedule beyond what is already available. Hence, the feeding buffer in this case will be changed by the activity float.

With respect to project 1, the feeding P1-1 and P1-5 has a feeding buffer of 2 days. However, the float of activity P1-5 is 9 days. So the feeding buffer of this feeding chain will be 9 days. In the project 2, there are two non-critical chains: P2-2 and P2-2, P2-4. The P2-2's activity float is one day equal to the feeding buffer size that is calculated according to RSEM; hence the feeding size of this chain is one day. Similar to P2-2, the feeding buffer of P2-4 is two days equal to the P2-4's activity float. Those feeding buffer are inserted and represented as depicted in Figure 12.

Based on the bar chart in Figure 12 and the Resource flow network that is depicted in Figure 11, in the project execution phase, the project manager can easily control the multi-project status through the buffer penetration. Any delay that occurs in any individual activity will be shown and controlled. For example, assumed that the activity P1-2 is delayed one day, immediately the project buffer 1 will be shorter 1 day. This means, the project buffer is consumed 25%, and this value falls in the *OK* zone (Figure 7) and this means no need of action or concentration. Nevertheless, the project buffer 2 is consumed to 33% because activity P2-5 is also delayed due to the resource flow with P1-4 (alert by resource buffer). This value falls into the *Alert and Plan* zone; this means the project manager must focus on the delay of activity P1-2 and prepare the methods to overcome or to fix the delay of activity P1-2.

The normal ways for this are often increasing the unit productivity of resources, renting external resources, changing the construction technology etc. The re-scheduling process is just implemented when the buffer is consumed over 100% (although rarely). When the re-scheduling is mandatorily implemented, the completed activities will be removed and then the proposed ROMPS is applied again with the remaining activities of multi-project.

5 ROMPS-ASSESSMENT

5.1 *The improved heuristic-priority rules method*

The main purposes of this section are to evaluate the impact of resource moving time when it is included into the multi-project scheduling process and the effect of the new secondary priority rule *Minimum Resources Moving Time (MinRMT).* Besides, the improved heuristic-priority rules method is also verified. This paper considers three cases as follows: (1) Considering the multi-project scheduling without the resource moving time (RMT). (2) Considering the multi-project scheduling with the RMT, but not applying the priority rules-MinRMT. (3) Considering the multi-project scheduling with the RMT and applying the MinRMT.

5.2 *Multi-project sample*

In the literature, the authors could not find any standard example for the resource-constrained multi-project scheduling problem. Hence, this paper refers to single project examples in PSPLIB (Kolish and Sprecher 1996), and then generating the multi-project examples based on the following rules:

– This paper constructs four multi-project scheduling examples corresponding with four types: J30 set, J60 set, J90 set and J120 set in PSPLIB. Each multi-project example contains 5 projects that are chosen at random of different single-project in each set type.
– Activities are subject to finish-start precedence constraints with zero minimum time lags. Each activity has a single execution mode with fixed integer duration as the examples in the PSPLIB. Activities are only scheduled when all required resource types are available.
– Resource capacity is calculated by adding the resource capacities of each single-project in the PSPLIB.

5.2.1 *Resource Moving Time*

In order to obtain resource moving time among projects that closely cements with real construction projects in Vietnam. A survey was designed that carried out in one of the largest State Owned Construction Enterprise (ThangLong Construction Corp.) of Vietnam. The investigation papers were sent to the project managers as well as the schedulers of all companies in this corporation who have from 5 to over 20 experience years in construction industry. 40 investigation papers were sent out with 40 papers returned, the response rate is 100%. According to the investigated results, the minimum value resource moving time among projects is one day and the maximum value is over five days. Therefore, this paper applies the resource moving time among projects which are determined as random in a range of 1 day to 5 days.

5.2.2 *Implementation method*

According to the researches of Lova and Tormos (2001) and Kolish (1996), the parallel schedule generation scheme (P-SGS) often outperforms compared to the serial schedule generation scheme. Therefore, to safe the calculation time, this paper only applies the P-SGS to generate the feasible multi-project scheduling. Besides, to clarify the role of resource moving time in the scheduling process that is based on the priority rules-heuristic methods; this paper has investigated all nine most widely used priority rules as presented in Table 1. In order to verify the achieved results, this

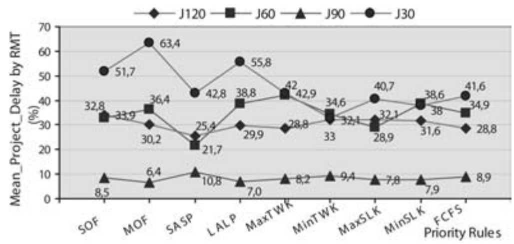


Figure 13. Resource moving time in Mean-project delays.

paper will use two criteria measurements corresponding to the single project approach and multi-project approach as presented in Lova and Tormos (2001):

The Mean-Project-Delay (Eq. 2) will be applied to estimate the increase of individual project durations caused by the resource moving time:

$$\textbf{Mean-Project-Delay} = \frac{\sum_{i=1}^{M} DI_i}{M} \qquad (2)$$

The Multi-Project-Delay (Eq. 3) will be applied to measure the increase of total multi-project duration results by the resource moving time:

$$\textbf{Multi-Project-Delay} = \frac{\mathrm{Max}\,(DI_i) - \mathrm{Max}\,(DR_i)}{\mathrm{Max}\,(DR_i)} \qquad (3)$$

Whereas: M is the number of projects in the multi-project system. DI_i is the different time between the resource-constrained project duration with and without resource moving time. DRi is the individual project duration under resource constraint condition as traditional calculation.

For simple calculation, this paper only focuses on the time that is used to move resources from a project to other projects. The time that is used to transfer the resources from the global resource pool (head office) to individual projects and within a project are assumed to take no time. The proposed heuristic-priority rules method has been coded using the Microsoft C# programming language and Microsoft SQL Server 2005.

5.2.3 *Results of the computational experience*

In order to confirm the correct performance of the proposed RCMPS-RMT process, the authors first applied it to schedule all four multi-project samples with unconstrained resource conditions. The achieved results are identical with the original project due dates that are supported in the PSPLIB. That is to say the proposed RCMPS-RMT is confident to scheduling the projects including resources moving time.

With *Mean-Project-Delay* criterion, the average project delays caused by the resource moving time (RMT) correspond to four multi-project samples

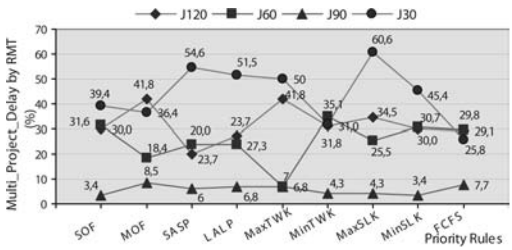


Figure 14. Resource moving time in Multi-project delay (%).

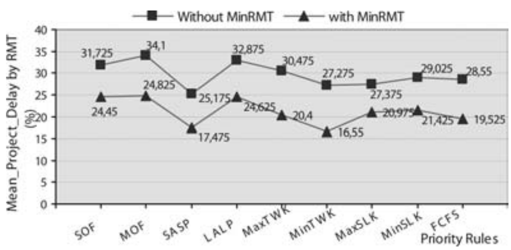


Figure 15. The reducing time when applying MinRMT (%).

(J120, J90, J60 and J30) are presented in Figure 13. All the heuristic-priority rules generated significant different results between the multi-project scheduling with and without RMT. The resource moving time has contributed to 29.3% average delay increase of individual projects.

With *Multi-Project-Delay criterion*, the achieved results are similar. The multi-project duration significantly increased to 26.60% average when the RMT is included into the multi-project scheduling process. The additional average multi-project delays when considering the RMT are presented in Figure 14.

These initial achieved results prove that the resource moving time among projects can not be ignored when multiple projects are deployed far from each others.

Figure 15 presents the comparison of the multi-project scheduling between the cases which apply and do not apply the proposed secondary priority rule MinRMT. In the case that the MinRMT is applied, the total project delays are reduced to 7.34 % average compared with the cases without MinRMT. This result shows the effective performance of MinRMT in the project scheduling process.

5.3 *Advantages of ROMPS in comparison with the original critical chain buffer management*

5.3.1 *Multiple resource types per activity*

Most Critical Chain Buffer Management (CCPM) researches to date assume that each project activity requires only single-unit renewable resources. This is a major departure from the classic job shop scheduling and Theory of Constraints job shop scheduling techniques in the manufacture domain. In construction projects, the activities always require multiple resource types and multiple units of each resource type. With the proposed ROMPS, schedulers can generate the project scheduling that includes the use of multiple resources per activity.

5.3.2 *Multi-project scheduling*

Most previous CCPM research works focused on single project management, issues and solution for dealing with resource-constrained multi-project scheduling were hardly paid attention. In practice, Critical Chain also offers a solution for multi-project program management organizations (Patrick 1999, Leach 2000). To handle the multi-project duration, the CCPM methodology first treat each project as a single project then release projects sequentially by staggering (ranking) projects based on the drum resource (bottleneck resource) as the heavily loaded resource across projects. The fundamentality of this method is just to resolve the resource conflictions by successive utilization with the bottleneck resources and to execute the projects as a project sequence (Lechler et al. 2005). The precedence of the projects in the resource competition is not explicitly supported by CCPM, except the priority rule first-come-first-served (the first project in the system will has the highest priority to get the required resources). Furthermore, the problems of the resource conflicts between non-critical resources are not directly addressed in CCPM. In practice, the construction projects often require high coordination of many resource types in the execution. If any type of the required resources is absent, it may cause the disruption of the whole project. Additionally, the construction projects are unique; hence there is a fact that not all projects are consistent in the use of the drum resource.

Based on the heuristic-priority rules method, the proposed ROMPS solution clearly depicts how to find a feasible multi-project scheduling with multiple resource types before inserting the buffers. These are the advantages that the original CCPM does not have.

6 CONCLUSIONS AND FUTURE WORK

This paper proposes a new solution – ROMPS – that based on four main processes takes the advantages of both the Heuristic-Priority Rules and the CCPM techniques. Therefore, it provides a certain level of stability in an uncertain execution environment that a traditional resource-constrained multi-project schedule often does not. Additionally, this paper incorporated the resource moving time among projects to the resource-constrained multi-project scheduling, which has not been considered in previous research. Though the characteristics of the multi-project environments in this research are mainly applied in the construction industry in Vietnam, the developed approach is applicable to other countries, especially to the developing countries which have a backward transport infrastructure.

In the construction phase, the buffer management information is updated continuously and accurately to help the managers make timely and effective decisions. Those problems require a useful tool to support the coordination between central manager and site manager and it must be based on an efficient and suitable system. For this, the advances of information technology play a very important role. This is also the future research that aims to support the proposed ROMPS with a prototypical implementation.

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BauVOGrid: A Grid-based platform for the Virtual Organisation in Construction

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ABSTRACT: A basic prerequisite for the success of every Virtual Organisation (VO) is the efficient cooperation of the participating companies. This is especially important for the construction industry which is characterised by one-of-a-kind products and one-of-a-kind projects, typically leading to complex project structures including intricate contractual relations, frequently changing tasks and high dependability on external factors (environment, transportation, socio-political aspects etc).

Such complex structures cannot be successfully managed by conventional technologies. In this paper we describe a platform for efficient VO cooperation and management that is being developed in the BauVOGrid project (2007–2010) as part of the German D-Grid research initiative (www.d-grid.de). The hypothesis is that such a platform can be best realised by the use of grid-based services combined with semantic methods and goal-oriented process management. The paper introduces the motivation and objectives of the project, presents the developed conceptual approach and the targeted short-term industry use cases and scenarios and details the project's contributions related to collaborative process management.

1 INTRODUCTION

1.1 *The Grid as VO enabler*

Virtual Organisations have emerged in recent years as an answer to various new socioeconomic demands such as virtual and agile manufacturing, lean production and concurrent enterprising. The Globemen project defines a VO as a "*customer solutions delivery system created by a temporary and reconfigurable ICT enabled aggregation of core competencies*" (Karvonen et al. 2003). These and other known definitions, e.g. from (Camarinha-Matos et al. 2005), emphasize the importance of ICT for a VO. While there are many other aspects that distinguish VOs from traditional organisations, such as differences in teamwork, management style etc, the efficiency of the used ICT infrastructure is a widely accepted prerequisite for the good performance of a VO.

One of the new paradigms regarding the realisation of such an infrastructure is the *Grid*. The term "Grid computing" was coined about 10 years ago to denote a form of distributed computing in which physically dispersed hardware and software resources are virtualised to provide applications with a single and powerful computing environment (Foster & Kesselman 2004). Within a Grid, the use of processing power and information storage can spread across physical locations and organisational boundaries, optimised through virtualisation and collective management, and largely eliminating the typical server bottlenecks of other approaches. The principal Grid architecture, as suggested in (Foster et al. 2001) is based upon the notion that effective VO operation requires sharing multiple relationships among the participants. It is defined in terms of a *layered set of open standardised protocols* enabling the development of standard middleware services that can provide enhanced capabilities for specific Grid-based VO environments (Figure 1). Moreover, the resemblance to the Internet Protocol Architecture makes it easy to map the Grid

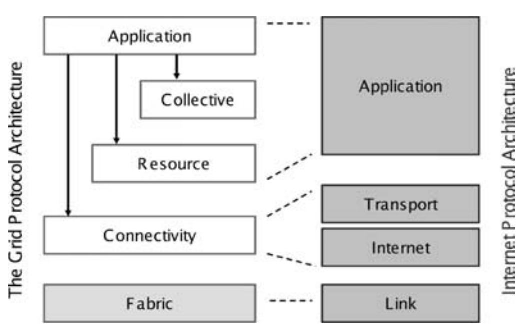

Figure 1. The layered Grid architecture and its relationship to the Internet protocol stack – adapted from (Foster et al. 2001).

components to the Internet layers, thereby ensuring Web-based interoperability.

Each of the five protocol layers presented on Figure 1 meets specific well-defined purposes having more or less direct relationships to concrete VO requirements and needs.

The *fabric layer* provides interfaces to the heterogeneous resources (computational utilities, databases, files, network resources, sensors etc.) to which shared access is enabled via the Grid middleware. Fabric components implement local, resource-specific operations triggered by operations on the higher levels.

The *connectivity layer* defines core communication and authentication protocols for Grid specific highly secure network transactions including transport, routing and naming, drawn from the TCP/IP protocol stack. The comprehensive secure connectivity solution provides several benefits to VO environments such as single sign-on, delegation of user rights to services and easy integration with local company security solutions.

The *resource layer* builds upon the connectivity layer to define protocols for the secure negotiation, initiation, monitoring, control, accounting and payment of sharing operations on *individual* resources.

The *collective layer* concerns the interactions across *sets* of resources. By bundling the services on the lower layers, this layer can provide a number of VO enabling functions, such as: directory services – allowing VO members to discover the existence and properties of various resources, brokering services – allowing VO members to request allocation of resources and schedule tasks on them, data replication services – enabling the management of VO storage, community authorisation services – enforcing group policies for resource access, and so on.

Finally, the *application layer* represents the "gridified" user applications in the VO environment. Such applications can fully use the functionality and power of the services defined at any lower layer, thereby enabling a structured approach to the development of flexible and dynamic VO infrastructures.

1.2 *Motivation and objectives of the BauVOGrid project*

Realisation of the Grid architecture outlined above can bring about many potential benefits to VO collaboration, management and interoperability in the full life-cycle of a VO. However, current Grid implementations are still mainly focused on research community needs and only partially fulfil the given promises. Various industry VO challenges such as the requirement for enhanced, yet easy to use security and authentication, concurrent processes, complex role-based authorisation and responsibility structures, dynamicity etc. remain not yet duly considered.

The German BauVOGrid project (BauVOGrid 2007) sets out to respond to these challenges. It develops a *Construction Community Grid* solution that aims at providing next generation VO services. The goal is to substantially improve the operability of virtual organisations in the construction sector via a flexible and reusable *grid-based platform* that will enable:

– controlled representation of responsibility and authorisation structures
– fast configuration and management of both global VO processes and local company-specific processes in accordance with the set up responsibility structure
– fast, flexible and secure access to information from different sources (documents, drawings, photographic material etc.), both from headquarters and from the construction site
– ad-hoc changes in the process flow, using semi-automatic process simulation
– capturing of processes and process/product data on the site making use of various mobile devices, thereby providing a basis for faster and more efficient decision making with participation of all site workers.

Achievement of these goals is grounded on the coherent, integrated use of four cutting-edge ICT technologies, i.e. (1) Grid, (2) Semantic Web, (3) Process Modelling and Management, and (4) Mobile Computing.

2 BACKGROUND

Extensive literature and best practice examples exist in all four ICT areas that provide the foundation of the BauVOGrid platform. The book by Foster & Kesselman (2004) presents a comprehensive overview of Grid technology, its various aspects and current applications, together with a rich set of further references. Similarly, Daconta et al. (2003) provide broad coverage of the concepts and techniques related to Semantic Web technology. The book by van der Aalst et al. (2007) spans the whole spectrum of business process management ranging from theoretical aspects, conceptual models, and application scenarios to implementation issues, whereas Scheer (2000) is specifically related to the explanation of the ARIS methodology used by BauVOGrid. Finally, mobile technology, as related to the scope of BauVOGrid is well detailed in (Shorey 2006).

However, whilst all these sources have been and are important and useful, BauVOGrid builds specifically on the findings of two prior projects. These are: (1) the EU project InteliGrid, and (2) the German project ArKoS.

The InteliGrid project (Dolenc et al. 2007, 2008) developed a general architecture and a set of generic services for Grid-based VO interoperability and management that clearly showed the importance and the place of a new semantic service layer in the Grid architecture. The developed services focus on various VO aspects with emphasis on the generality of the provided solution. On middleware level services for OGSA-DAI-based data access, Grid authorisation (GAS) and Grid resource management (GRMS) have been developed whereas on the business service level a PDM service, a DMS service and several analysis/simulation services from the AEC domain have been prototyped and demonstrated. They are supported by a set of interoperability services on the introduced new semantic service layer encompassing Gridspace management, VO Management, Service Management and Resource management (Gehre & Katranuschkov 2007).

The ArKoS project (Scheer et al. 2004, Keller et al. 2006) developed a framework for the management of collaborative scenarios consisting of methods, tool support and an integration platform extending the ARIS approach for the needs of VO collaboration. ArKoS provides integrated support of cooperation intensive cross-enterprise business processes. The achieved generic solution concept has been transferred into an industry-specific reference model for the construction industry, thereby providing proof of concept and valuable input with regard to process model modularisation.

Extensively and rationally utilising the results of these project, BauVOGrid conceptually integrates and further extends their findings into a new, process-centred and strongly practice-oriented platform approach. Its major issues are discussed in the following sections.

3 THE BAUVOGRID APPROACH

3.1 *Project structure and partnership*

To put the theoretical discussion of the BauVOGrid approach in the correct scope, at first a concise overview of the project portfolio will be given.

The project runs from June 2007 to May 2010 and is divided into 7 RTD and 2 supporting work packages (cf. BauVOGrid 2007). The first include specification of user requirements and scenarios (WP1), development of the system architecture (WP2), semantic AEC services (WP3), process modelling and grid-based workflow management services (WP4), mobile grid-based information management services (WP5), realisation of a BauVOGrid community portal (WP6) and validation in a pilot demonstrator (WP7). The latter are dedicated to dissemination, exploitation and project management activities.

The consortium comprises one academic partner (the Dresden University of Technology), two research organisations (the Fraunhofer Institute FIRST and the Institute for Information Systems (IWi) at the German Research Center for Artificial Intelligence (DFKI)) one know-how transfer facilitator (TransMIT) and five industry partners, including two large construction companies (Bilfinger Berger and BAM Deutschland), two software vendors from the AEC domain (RIB Information Technologies and SEIB ITC) as well as a business software vendor (IDS Scheer AG). This considerable industry participation emphasises the strong practice orientation of the project which becomes also visible in the developed platform approach.

3.2 *Basic concepts*

The suggested BauVOGrid platform takes into account existing reference data structures in the construction industry as well as Grid and general ICT-standards and reference implementations such as the Globus Toolkit, OGSA-DAI, WSRF, OWL/OWL-S, WSDL, SOAP and BPEL. Combining Grid, Semantic Web, Process Modelling and Mobile Information Management technologies, it focuses specifically on the Grid-based virtualisation of resources and process-centred information management built upon the ARIS Methodology of Business Engineering (Scheer 2000).

The use of *Grid technology* enables efficient data and performance distribution in the heterogeneous network of servers, workstations and mobile devices within a VO, as well as high quality of authorisation, authentication and access control management. To provide for the latter, semantically grounded *role-based* authorisation and access control taking into account actual VO roles is applied, thereby extending the currently favoured Grid VOMS model (Katranuschkov et al. 2008).

The use of *Semantic Web technology* enables the common semantic commitment (and therefore the interoperability) of all involved applications and services via an explicit ontology specification providing consistent representation of the resources, services, users, roles and processes in the VO. For that purpose, the core ontologies developed in the InteliGrid project, namely (1) organisational, (2) resource, (3) service, and (4) business process objects (BPO) ontology (cf. Gehre et al. 2006), are used and respectively adapted and extended. Such extensions are required especially with regard to the BPO ontology to enable the targeted collaborative process management. This is discussed in more detail in Chapter 4.

Appropriately coupled with the respective ontological specifications, the use of advanced *Process Modelling and Management methods* provides for coherent top-down description of processes starting from a top-level value chain down to executable *business process objects* (BPO). This allows also realisation of a two-stage workflow management including: (1) the composition, instantiation and execution of BPOs on the basis of predefined process templates (business level workflow), and (2) the orchestration and execution of Grid services and applications (service level workflow, encompassed in the business level).

Last but not least, via the *Mobile Technology* context sensitivity with regard to the location, role and profile of the site workers as well as the specific features of the used mobile devices will be made available. The use of mobile services is without doubt an essential prerequisite for the achievement of adequate ICT support on the construction site, but in order to be efficient these services must also commit to the common platform ontologies in their relevant parts, conform to the overall platform architecture, and be prepared to tackle specific mobility problems such as temporary connectivity losses, synchronisation and replication issues etc.

An essential final proposition regarding the envisaged VO platform is that, whilst central to the approach, Grid technology is only seen as an "enabling" and not an "all encompassing" issue. Bringing about many benefits it should not constrain other collaboration possibilities. In practice, a VO may apply multiple ICT infrastructures concurrently, such as client-server subsystems, Web Services and Grid. An efficient Grid-based approach must take that into account, and not assume a "holy grid world".

3.3 *Platform architecture*

Realisation of the platform, enabling coherent integration of the abovementioned technological issues, can be successfully achieved on the basis of a *layered architecture* that allows for clear and well-defined interrelationships and interfaces between grid middleware components, basic VO services, business process services, and engineering services and applications. Furthermore, the platform should be supported by a homogeneous semantic model of the environment, facilitating the system-wide identification of all involved users, resources and services – regardless of their particular location, but obeying strict role-based access profiles.

The right part of Figure 2 below shows the principal layers of the suggested platform architecture in comparison with the original Grid architecture from Figure 1.

It is easy to see that all Grid layers are principally preserved (the three middleware layers being put together in one box only to save paper space). However, they are additionally extended by three new layers in the BauVOGrid architectural approach (the three black boxes on the right hand side).

The *Semantic Grid Services* layer is largely adopted from the InteliGrid project and has the same intention and meaning (cf. Dolenc et al. 2007). It contains all

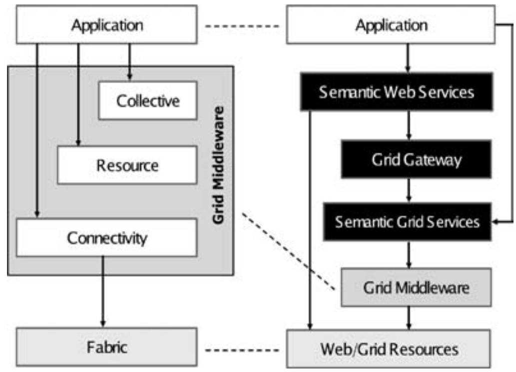

Figure 2. The extended BauVOGrid architecture (right) compared to the original Grid architecture (left).

supporting ontology-based VO management services that are responsible for the provision of semantically rich queries and assertions with regard to users, resources, service access etc.

The next two layers, i.e. the *Grid Gateway* layer and the *Semantic Web Services* Layer are missing in InteliGrid and various other known approaches focusing on pure grid environments. Their purpose is to enable co-existence of web service based subsystems and advanced fully gridified applications. Due to the high security standards imposed by the Grid middleware – a major benefit for each industry VO – such co-existence is per se not given.

The Semantic Web Services are in fact normal Web Services defined using WSDL. The term "semantic" is applied here to denote that, as all other high-level services, the services on that layer have to commit to the platform ontologies in their relevant areas of interest. This can be achieved by implementing them either to fully "understand" the relevant parts of the OWL-based ontology specifications or, in a more light-weight approach, by taking care that the relevant subset of queries/responses to the ontologies are properly interpreted and served.

The purpose of the intermediate *Grid Gateway* layer is solely to provide the necessary mechanisms that would allow acceptance of the Web Services in the Grid environment. This can be achieved via dedicated proxies utilising so called *short lived service credentials*, checked against the content of the VOMS database. In this way, a minimal automated gridification of non-grid services and tools takes place.

Engineering applications have two principal possibilities to plug-in to the platform. The first includes comprehensive gridification, thereby enabling full use of all grid middleware features and direct linkage to all semantic grid services. However, this is also the more difficult and resource-consuming approach, requiring full or at least partial re-engineering of the application. For its achievement, various methods can be applied depending on the actual goals and the specific application context (Mateos et al. 2007). The second possibility, favoured in BauVOGrid, is of more pragmatic nature. Its essence is to first provide a web service wrapper for the application logic which is itself wrapped by a grid service wrapper via a standard conversion procedure utilising the functionality of the Grid Gateway layer. This has two advantages: (1) easier way towards gridification for domain developers, due to the clear separation of gridification techniques from the application logic, and (2) co-existence of both grid and web services in the same VO environment and eventually for the same end-user systems, thereby avoiding a mandatory grid solution (Katranuschkov et al. 2008).

3.4 *Pilot implementation scenarios*

The outlined *platform* approach implies various adaptation/instantiation possibilities for different targeted application areas that can be potentially realised as distinct VO environments serving dedicated construction related purposes. However, an important goal of the BauVOGrid project has always been the achievement of practical short-term benefits for the industry, which can only be accomplished by clearly defined pilot implementation scenarios at the project outset. Therefore, considerable efforts have been spent in the first project phase for (1) selecting relevant scenarios out of a large number of drafted candidates, (2) providing a reference real-world project for a pilot demonstrator, and (3) providing a reference process model for the later process collaboration services. The result is a well-documented scenario for *Mobile Collaborative Defect Management*, including the sub-scenario *Media Management* (Katranuschkov & Lehner 2008).

Defect management involves three types of actors that need to collaborate for the achievement of fast and cheap problem solutions, even though their views and positions may often be controversial. These actors are: (1) the Owner, (2) the Main Contractor, and (3) the Subcontractors. Typically, their contractual relationships can be expressed as 1:1:N, but complex cases as 1:M:N or even $L{:}M{:}N_1{:}N_2{:}\ ..\ {:}N_x$ need also be considered. On a large construction site, like the selected reference project *ARGE Campeon* shown on Figure 3, 10000+ defects may occur during the construction phase. As considerable cost factor these defects need to be duly managed, largely in parallel. However, whilst circumstances, cause and effect can vary, the process itself is generally the same. Taking that into account, a *reference defect management process model* has been developed, comprising 57 functional subtasks.

Figure 3. View of the construction site of the BauVOGrid reference project *ARGE Campeon*: The Infineon Headquarters at Neubiberg near Munich – gross area 250000 m^3, total costs 240 MEuro, constr. time 18 months, 140 sublocations to be managed.

These range from simple message processing to document and media management activities. The latter include taking photos and videos, voice recording, matching earlier photos to a specific event, classifying the media data and so on. Considering the large number of parallel workflows between the involved actors, especially with regard to the main contractor, explains the importance of an adequate collaborative process management. How this is being solved by BauVOGrid is outlined in the next chapter.

On Figure 4, the actual components of the VO environment for the planned pilot demonstrator are presented, underpinning the hybrid nature of the BauVOGrid architecture shown on high-level in Figure 2.

As the figure illustrates, the basis of the environment is the Web where the three major end-user defect management systems (DfMS) provided by SEIB ITC (for the Owner role), the Bilfinger Berger subsidiary *bebit* (for the Main Contractor) and RIB (for the Subcontractors) are installed. These three systems are "plugged-in" to the BauVOGrid platform via the Gateway layer as explained in section 3.3 above. By doing that, access to all infrastructure services of BauVOGrid will be provided, including a Central DfM Service, a Media Management Service, a Workflow Management Service etc. However, all these details remain completely irrelevant to the end users who can use the platform via standard web browser or specialised stand-alone clients. The only thing they have to do in order to reap the benefits of the Grid solution (virtualised resources, faster access and quality of service, enhanced security, comprehensive process support etc) is to be properly legitimated in a single sign-on procedure.

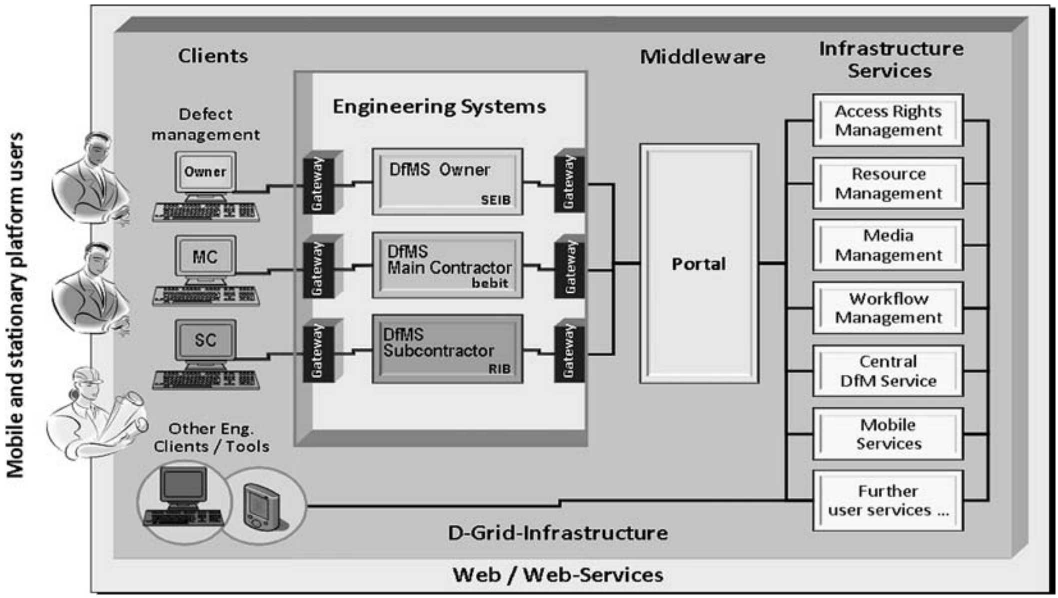

Figure 4. Actual components of the envisaged BauVOGrid pilot demonstrator.

4 COLLABORATIVE PROCESS MANAGEMENT WITH BAUVOGRID

4.1 *Basic concepts*

Collaborative processes in construction are marked by high dynamicity and can therefore not be managed by conventional process modelling and management techniques. In BauVOGrid a modular approach using the ARIS methodology and extended Event-Driven Process Chains (eEPC) as baseline for process modelling is suggested (Katranuschkov et al. 2007, Scherer et al. 2008). It is grounded on the semantically consistent integration of eEPCs and BPOs in description logics (DL). These three representation methods are first concisely introduced below.

eEPCs (Scheer 2000) have become a de facto industry standard in the German speaking countries. Unlike most process modelling notations, eEPCs include also elements for the involved data, organisations and resources, thereby integrating the four different aspects *event*, *function*, *system/service/data* and *organisation* (see Figure 5).

Business Process Objects (BPOs) have been first suggested in the InteliGrid project (Gehre et al. 2006). A BPO is understood as an extension of currently known Business Object specifications in that it enables better and more consistent binding of a real-world concept, representing a product or service which is the goal of a business activity, with the actual business process for its realisation. BPOs enable flexible modularisation of eEPCs as well as the definition of process patterns

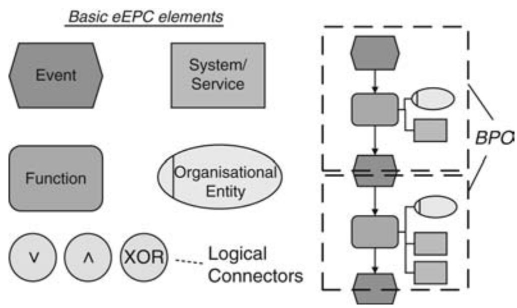

Figure 5. Basic eEPC elements (left) and illustration of the principle of eEPC modularisation with the help of BPOs (right).

that can be used as building blocks for the specification of dynamic (ad-hoc) workflows. Moreover, by representing them in DL, consistent process formalisation can be achieved.

Description Logics (DL) are a family of logic-based knowledge representation formalisms designed to represent and reason about conceptual knowledge. In BauVOGrid we especially concentrate on the ALCQI DL as a significant fragment of OWL-DL, in which conservative extensions are still decidable in 2-EXPTIME (Lutz et al. 2006). A DL knowledge base usually consists of a set of terminological axioms (often called TBox) and a set of assertions (often called ABox).

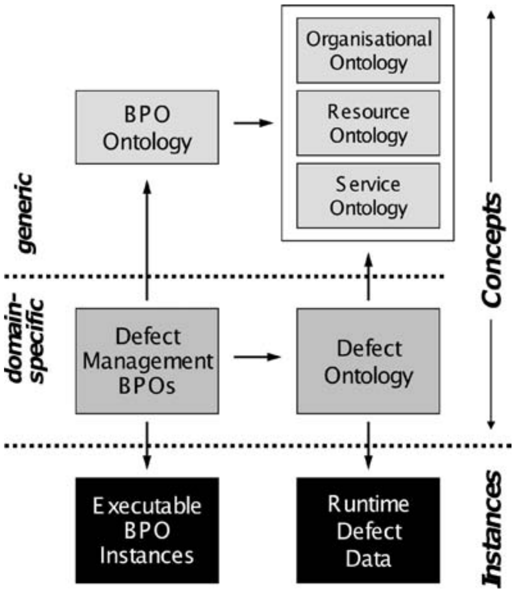

Figure 6. The BauVOGrid system of ontologies on the example of the Defect Management Scenario.

4.2 *Building the knowledge base for collaborative process management on the example of the developed defect management scenario*

The DL knowledge base for collaborative process management is built in *three principal stages* – the first on generic, eEPC/BPO level, the second on domain-specific conceptual model level, and the third on run-time instance level. This is done via a layered system of inter-related ontologies. Figure 6 below shows the ontologies used for the discussed defect management scenario.

At first a *generic BPO ontology* which describes the main features of eEPC and encompasses the definitions regarding the BPO concept is created. This is done at the platform's development phase whereby, as already mentioned, the ontologies developed in the InteliGrid project are respectively adapted and used.

The *Organisational Ontology* defines the concepts related to the structuring of a virtual project organisation (VO), i. e. VO actors, persons, organisations, roles, together with the respectively applicable access control and authorisation constraints.

The *Resource Ontology* is dedicated to the (meta) representation of all data resources available in the project environment (files, documents, product model views etc). It does not contain any actual documents or product model data as such.

The *Service Ontology* describes the available services, IT subsystems and tools referenced by the definitions of the other ontologies together with the exchanged/provided content and the conditions for service use.

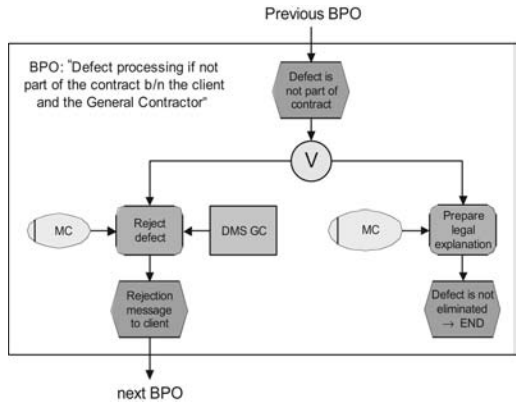

Figure 7. Example BPO from the developed reference eEPC for defect management.

Referencing these three ontologies the *BPO Ontology* provides an encompassing view on the distributed environment, enables direct relationship to business processes and the related business requirements, and can even be used as basis to support workflow management. The BPOs correspond to non-overlapping fragments of the eEPC, partitioned by one or more well-defined criteria. This is on-going work described in more detail in (Scherer et al. 2008).

On the basis of these generic definitions, in the second stage the specific ontologies for Defect Management are constructed. This is done at the platform's configuration phase, whereby an ontology called "*Defect Management BPOs*" that specialises the BPO/EPC concepts on the higher level, and a "*Defect Ontology*" that describes the data for the defects itself via specialisation/extension of concepts from the Resource and Organisational ontologies are defined.

The knowledge representation of the above ontologies consists only of TBoxes. Process instantiation happens at *run-time*, so that the ABox has to be created at the third stage. Here the BPOs for a concrete process have to be instantiated as well as referenced with the run-time data corresponding to the resource specifications for a process.

In Figure 7 a fragment of the eEPC for defect management is presented. It corresponds to one BPO classified by the responsibility of the Main Contractor (MC) for the execution of a technically related group of functions. The whole developed eEPC containing 57 functions is modularised into 11 such BPOs containing between 1 and 7 functions. This modularisation plays an important role for the efficiency of the process management on the construction site.

An example run-time ABox for the shown BPO comprising 30 logical assertions is provided in (Scherer et al. 2008) where a step-by-step discussion of their creation is also presented. Using the described formal approach, pattern-based collaborative workflow definition and management can be efficiently achieved.

5 CONCLUSIONS AND OUTLOOK

In the preceding chapters of this paper, the major aspects of a novel grid-based platform for VO operability in construction being developed by the German BauVOGrid project were presented. These include the developed flexible architectural approach, the established coherent ontology-based integration of the components, the suggested systematic method for dynamic process modelling and the conception of knowledge-based collaborative process management.

In chapter 2 it was mentioned that BauVOGrid builds upon the results of two prior projects, InteliGrid and ArKoS. However, whilst there is certain resemblance between BauVOGrid and these projects in several aspects of the presented approach, there are also a number of essential extensions.

Firstly, whilst InteliGrid developed a "pure" Grid-based ICT environment, BauVOGrid takes a more practice-oriented approach, anticipating the fact that in practice a VO will possibly apply multiple ICT infrastructures concurrently, and not assume a "holy grid world".

Secondly, the BPO Ontology that has been only initially drafted in InteliGrid is considerably enhanced and extended, related to actual process management services and brought to a mature deployable model. Moreover, in BauVOGrid the logical foundation and the criteria for the definition of business process objects (BPO) and business process patterns (BPP) are being worked out. The latter are especially interesting as building blocks for dynamically created workflows.

Thirdly, BauVOGrid develops a method for automated translation of BPOs to executable BPEL statements, thereby bridging the gap between ontology-related and process-related modelling efforts.

Fourthly, the high-level reference methodology suggested in ArKoS is brought to real deployable models in a distributed grid environment, pushing ArKoS business modelling concepts into technical engineering practice.

Last but not least, while InteliGrid and ArKoS focus on distinctly separated ICT areas, BauVOGrid creatively combines their results aiming at the achievement of much higher practical benefits from the involved technologies.

At this stage of work, the BauVOGrid project has identified user requirements and scenarios and has developed the overall platform architecture. A first practical prototype implementation of the scenario regarding defect management in the construction phase and revealing various interactions between the building owner, the main contractor and the involved subcontractors is under development and is expected to provide first validation results of the outlined concepts by the end of 2008.

The final BauVOGrid solution is expected to deliver new business perspectives both to construction practice and to software providers. It shall also enable VO-adequate use of domain-specific computationally intensive simulation, analysis and presentation tools developed by the project partners or by third parties, taking into account organisational, legal and technical constraints of construction VOs.

ACKNOWLEDGEMENTS

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Smart buildings and intelligent automation services (control, diagnosis, self-maintenance and adaptation, AAL,. . .)

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Context-adaptive building information for disaster management

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ABSTRACT: Up-to-date information about large buildings affected by an incident highly ease disaster management. Real-time data about the current status of the building generated by sensors or by emergency staff help gaining an overview of the situation. This document introduces a context-adaptive building information model for a computer aided disaster management system. It defines facilities to combine static and dynamic data in one consistent information model. The model integrates elements to allow for improved indoor positioning of emergency forces and context-adaptive displaying of information. Data collected by sensors that are installed in the building are embedded. Furthermore a link to a static model built up with a finite element program is established to enable an ad-hoc structural analysis of damaged structures. Sharing data with widely used CAFM applications promises fast deployment and high acceptance.

1 INTRODUCTION

The number of large buildings in today's cities is growing. Everyday life increasingly takes place in large real estates in urban areas such as big and widely ramified shopping malls, office buildings and centres for education and public transport. These buildings may be difficult to control and manage even under normal circumstances. The situation is aggravated in the case of extraordinary events like fires, earthquakes or terrorist attacks. To provide efficient disaster management it is necessary to gain an up-to-date overview of the site affected. In this context it is important to know the exact position of all the rescue forces on the real estate and to keep track of the status of the building under consideration. This implies keeping track of the accessibility of certain building parts and the information collected by sensors installed in the building. Furthermore it should be possible to perform an ad-hoc structural analysis of the building in order to react to possibly collapsed structural bearing elements like walls or beams.

Currently, information is normally gained from traditional 2D-floor plans and maps. They may be based on Computer Aided Design (CAD), Computer Aided Facility Management (CAFM) or Geographic Information Systems (GIS). Their effectiveness is limited since these plans and maps do not fulfil the requirements of modern disaster management. To address this problem, at the Institute for Building Informatics of Graz University of Technology a context-adaptive Computer Aided Disaster Management System (CADMS) is under development. The area of indoor positioning constitutes the core component of the system. Information about the current status of the building, its elements and its structural behaviour should be shown to the user in a context-sensitive way.

Unfortunately there are no mature technologies that are able to compute the current position of human beings within buildings with an adequate accuracy, not to mention the special case of indoor positioning during an incident. Nevertheless a few techniques approaching the problem of positioning can be outlined.

The signal amplitude of the global navigation satellite system (GNSS) is too weak to correctly determine the position inside a building. Current receivers with enhanced sensitivity are able to detect the position, but this does not work for areas deep inside the building and for subsurface floors (Wieser 2006). Due to this reason high sensitivity GNSS cannot be used in disaster scenarios. Indoor positioning relying on installed infrastructure is not suitable for disaster management because of the fact that this kind of device may be destroyed or affected in some other way during the incident. Thus, it is neither an option to apply Radio Frequency Identification (RFID) tags in the building nor to work with installed WLAN infrastructure. Further, positioning based on GSM/UMTS transmitters close to the real estate is not suitable.

Ultra-Wideband (UWB) yields a relatively high accuracy in positioning when using several 'drop units' that act as amplifier and repeater to ease the low coverage of a single UWB transmitter. The task of placing these amplifiers in the building – which would have to be accomplished by the action forces during the deployment – may detract them from their important and extensive job onsite.

For all these reasons position determination in the CADMS is based on inertial navigation. Inertial Measurement Units (IMUs) mounted on the rescue workers' feet or on the upper part of the body allow for infrastructureless indoor positioning. Beginning at a defined starting point in the building or somewhere in its surrounding area and tracking the movements of a person by numerical integration of the sensor's acceleration, the current position can be determined. Over time the measurement errors grow and therefore the exact position cannot be calculated relying exclusively on the technique of inertial navigation (Beauregard & Haas 2006).

To support the process of indoor positioning and to improve its results, the CADMS uses structural information about the real estate and incorporates it with the data collected by the IMUs. Having the knowledge about the exact location of the building's elements, the actual path of a person that seems to walk through a wall located close to a door can be corrected by adjusting it in such a way, that it crosses the door and not the wall, for example.

Following this argument, during the deployment the emergency forces carry IMUs and small robust computers with them. These devices store all the information regarding the real estate available in the building information model. The mobile devices must not represent an extra burden for people involved in the deployment. The current position of a person is presented on digital floor plans on the head mounted display. This position is transmitted to all the other service customers of the CADMS via a wireless network to enable the displaying of the positions of remote rescue teams, also.

This paper outlines an intelligent, context-adaptive building information model (BIM) including all the information necessary for effective disaster management. The information stored in this rich BIM is exploited by the CADMS and includes data describing the elements of the real estate and their accessibility, information about bearing elements and capabilities for integrating dynamically generated data like positioning information and user input. As a result, the CADMS based on this BIM allows for improved indoor navigation and context-adaptive displaying of information about the real estate affected. The CADMS enables the fast structural analysis of damaged buildings to initiate an evacuation when necessary and consequently to save lives.

2 REPRESENTING INFORMATION CONCERNING BUILDINGS

A context-sensitive building information model represents a building with its properties or an entire real estate, respectively. Furthermore it is able to respond to information from the environment and to start certain activities, such as the lowering of the temperature in a room due to changing climate. Efficient disaster management like it is accomplished by the CADMS depends on such a context-adaptive BIM. There are some different approaches to storing information on buildings. They should be investigated concerning their suitability for disaster management.

Digital floor plans used and created by conventional CAD applications represent a graphical view of the building's floors. They usually do not include any information on semantics necessary to show further information regarding adjacent rooms and doors leading to the outside of the building, for example. Luckily, such digital CAD plans are available for the most large real estates in the industrialised countries.

3D-data models contain alphanumerical data and represent the real estate's composition of several smaller entities like buildings, rooms and floors. These 3D-models can be extended with specialised capabilities for certain demands forming rich data structures for product modelling. The Industry Foundation Classes (IFC) data model developed by the International Alliance of Interoperability is an object-oriented, platform independent and open specification (Liebich 2006). It is the state-of-the-art modelling language for BIM and can be expressed by IFC-XML to ease the exchange of 3D-models between the software applications of different producers (Nisbet 2007). For the usage in disaster management it is necessary to have an overview of the affected site as soon as possible. This can be achieved more appropriately by displaying the current position on 2D-plans rather than in complex 3D-models, since they need more time to be fully comprehended by the onsite staff during disaster scenarios. Besides that, the major drawback of IFC is that it is not well introduced in practice yet, especially not in building documentation or CAFM. This will not change in the near future because it is too much effort to create and redefine 3D-models for older buildings. For this reason the IFC representation of real estates is not used as the underlying BIM by the CADMS at the moment.

The CADMS should have the ability to be adopted for as many of today's real estates as possible. Many of those real estates are managed by CAFM applications which combine floor plans imported from CAD systems and alphanumerical data necessary to administer the buildings. For these reasons the CADMS uses an enlarged CAFM system for the creation of the digital representation of real estates. CAFM information constitutes mainly static information that does not have to be updated in the daily process of facility management regularly.

Information for disaster management consists of highly dynamic information, like sensor data, but static data as well, which can be partly extracted from existing CAFM systems. This situation is shown in figure 1.

Extending the input module of CAFM systems with functions for entering further information like doors, walls, staircases and reference points all the data necessary for an extensive digital description of the building for a disaster scenario can be collected. The intelligent BIM suggested in this document defines which information has to be extracted from an enlarged CAFM application to serve as the basis of computer aided disaster management. The building model representing the status of a real estate consists of static data which is already determined at the beginning of the deployment. The CADMS has the flexibility to adapt the information contained in the BIM according to dynamic data received by emergency staff and by sensors during the deployment. Therefore it is possible, for example, to mark the location of trapped people or to change the colour of doors that cannot be passed any

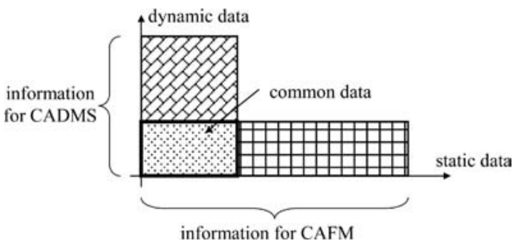

Figure 1. Disaster management and CAFM partly share the same source data.

more on the digital floor plans. Figure 2 depicts that the CADMS relies on two main data sources: static data collected by enlarged CAFM systems before the deployment and real-time data generated onsite.

The BIM is stored on every service customer's device involved in the deployment to circumvent the consequences of deep fades disturbing the wireless network connection. As soon as the network is available again the information contained in the BIM is synchronised with the other instances to keep the data consistent among all the rescue teams and the control room.

3 CONTEXT-ADAPTIVE BUILDING INFORMATION MODEL FOR DISASTER MANAGEMENT

This section describes the BIM which can be exploited by the CADMS to allow for effective disaster management.

3.1 *The BIM's requirements*

There are two main requirements the information model has to meet.

Firstly, it has to represent all the facts about the real estate that could be beneficial for the onsite staff during an extraordinary event. This includes digital floor plans, alphanumerical data concerning rooms and staircases and so on. Furthermore the CADMS should be able to interpret ingressing dynamic data

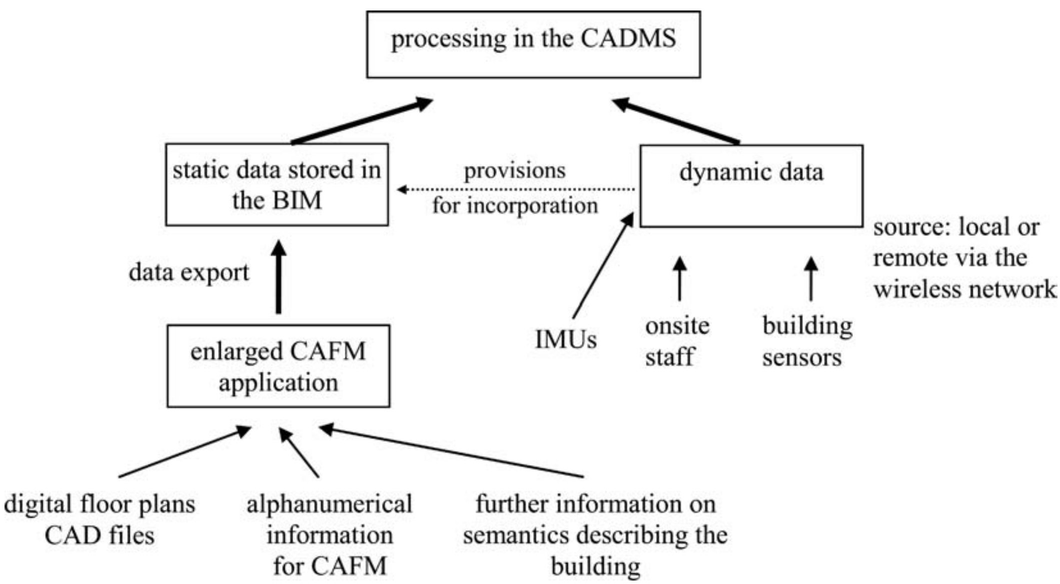

Figure 2. The CADMS embeds static data stored in the BIM and dynamic data gathered from sensors.

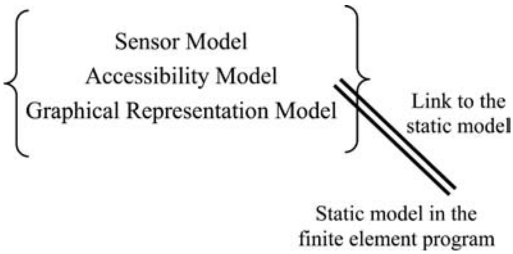

Figure 3. The BIM consists of three submodels and is linked to a static model.

regarding the current status of the building, it should for example be able to display a room's temperature. For this reason the BIM also has to store information about sensor devices installed in the building and about how to process their retrieved data. The handling of real-time data is required. The current condition of the building regarding its bearing elements like walls and beams is also included in the data describing the building. Therefore the BIM has to integrate elementary information about these bearing elements and the references to a structural model of the building created with a finite element program, respectively.

Secondly, all these information should not be presented as a long list of facts the onsite staff has to go through, but it should be presented in a context-adaptive way to the user. This means that the information the CADMS shows to the user depends on its current location inside the building. Besides that, indoor navigation should be possible for the members of rescue teams on their way through the real estate. This implies that the BIM also has to store information needed especially for indoor positioning, like the exact location of doors and reference points.

The developed BIM brings together all the data resulting from these two heterogeneous requirements in one consistent model.

3.2 *Model design*

The proposed building information model is divided into four categories covering different domains. Information stored in the BIM can be assigned either to the Graphical Representation Model, the Accessibility Model, the Sensor Model or it can constitute a reference to a static model built up in a finite element program. Figure 3 presents the overall design of the building information model.

The BIM data can be represented by different means. In the case of the CADMS developed at Graz University of Technology it is exchanged by files in the well-known XML format. The next sections explain the four parts of the BIM.

3.3 *Graphical Representation Model*

Since the Graphical Representation Model contains the graphical information in displayable formats, it serves as the fundamental part of the whole digital representation of a real estate. 2D-floor plans generated by CAD applications and imported by the CAFM system are utilised. The XML files only consist of some well-defined primitives: points, lines, polygons and arches. This means that the Graphical Representation Model does not contain any information on semantics, but only the plain scalable graphical representation of the building's floors.

These floor plans have to present a precise overview of the floor entered by the user. Hence they must not include further graphical information like room numbers, their intended use or conduits not clearly visible onsite. To ensure clearness this information may be added only in real-time and in a context-adaptive way by the CADMS. If the floor plans retrieved from the CAFM application contain such information, it must appear on a separate layer. This enables the removing of excess information from the floor plans shown on the head mounted displays. Due to the fact that the graphical representation is embedded into the BIM this information can be changed during the deployment. Parts of the building threatened with collapse can be marked to make rescue teams avoid entering the affected rooms, for example.

3.4 *Accessibility model*

All the alphanumerical information describing the real estate and utilised by the indoor positioning module of the CADMS is stored in the hierarchical Accessibility Model. Amongst others this encompasses: rooms with their attributes (e.g. number, intended use), room polygons to describe the location and the borders of a room, areas allocated to certain rooms to achieve a finer granularity, areas outside the building, all kinds of transitions between rooms and buildings (doors, windows), transitions connecting to the surrounding area, staircases, ramps, ladders and elevators.

The exact location and the properties of dangerous goods are also included in this submodel, which can be enormously important in the case of an incident. Furthermore knowledge on reference points is available in this category of the BIM. By knowing the exact location of reference points the CADMS can adjust and correct the results of the position determination degraded by measurement errors of the IMUs. Each position inside the borders of the real estate that can be clearly identified and recognised by the onsite staff can act as a reference point. These can for example be doors, fire extinguishers and light switches.

The Accessibility Model combines these pieces of information in a structured model with references between the objects. In this way a hierarchy from the

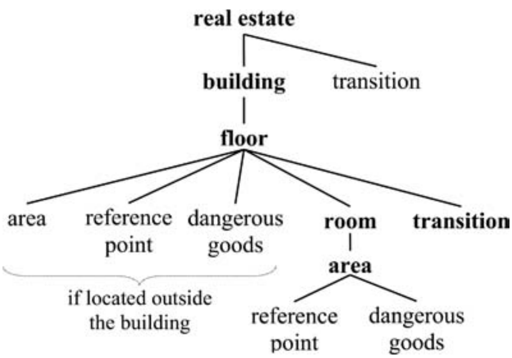

Figure 4. The accessibility model offers a hierarchical organisation.

real estate on the top, down to reference points on the bottom, is introduced, like it can be seen in figure 4. Reference points and dangerous goods are assigned to rooms or areas if they are located inside the building. If there are also objects that might become relevant to the deployment with a location outside the walls of the building, they cannot be linked to a surrounding room. In this case they are assigned to the floor for which they are defined. Following the connecting lines in figure 4 it is possible to show all dangerous goods inside a building or to highlight all the rooms that can be reached by only one door transition from the room the rescue worker is currently located in.

There are several types of transitions defined in the BIM. Information concerning transitions is used for indoor positioning and the context-adaptive displaying of information. A transition can define the exact area a person inside the building has to cross to enter another element in the model. Doors represent transitions between rooms, for example. When changing the room the route covered must not intersect the room polygon except at the location for that a door transition is defined. Windows can be seen as transitions as well. They can only be utilised as a transition to the surrounding area under certain circumstances (e.g. the vertical distance above the ground is not too large) defined in the window objects in the BIM. Ladders and elevators act as transitions between different floors and floor plans, respectively. When crossing a vertical transition the file loading process of a certain floor plan stored in another XML file can be initiated in the CADMS.

The automatic correction of imprecise measurement results from IMUs can be performed when entering another room since there are only some physically possible paths to change the room. Sometimes one is confronted with areas within rooms that can also be entered only by crossing some well-defined positions. In roomy real estates like airports or shopping malls there are often large rooms consisting of many

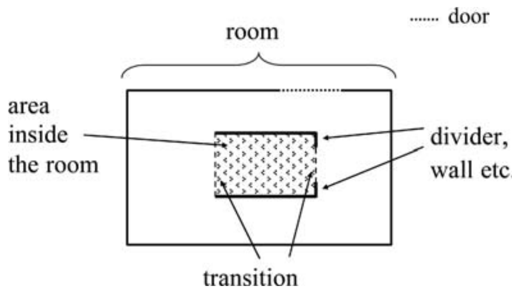

Figure 5. Areas can be separated from each other by transitions.

areas that are partly separated from each other by walls, balustrades or dividers. They logically still form one single room in facility management and therefore in the BIM also. Different shops separated by lightweight walls made of glass belonging to a shopping centre may offer such a situation which is symbolically depicted in figure 5.

To represent the constellation in figure 5 a room has to be defined, which means that the corresponding room polygon and some describing properties have to be entered into the CAFM application to be added to the Accessibility Model. The area inside the room is modelled as an area object. Since this area is physically separated from the surrounding room it should be possible to perform the automatic correction not only when a service customer enters the room, but also when he enters this area. To make this possible the CADMS needs to have the knowledge of the location where there are no dividers around the area. To achieve this goal these locations are modelled with generic transition objects although they do not represent a room transition between different rooms. When walking over this virtual transition inside the room and entering the shop the members of a rescue team may not even notice that they are crossing an area that is defined as a transition object in the BIM.

Each floor plan and its corresponding static information are stored in their individual XML file. Since the deployment during an extraordinary event may not be limited to one floor or even to one building, the CADMS must allow for reloading data belonging to different floors during runtime. When a user of the CADMS leaves a building and approaches another one or when he uses a vertical transition between different floors the system can automatically load the according information into the computer's memory. Generic transition objects between the buildings define which areas have to be entered to initiate the reloading process. Therefore the information about the area located in the surrounding of the buildings and the four reference points in figure 6 becomes automatically available when a person leaves building 1 and walks in the direction of building 3.

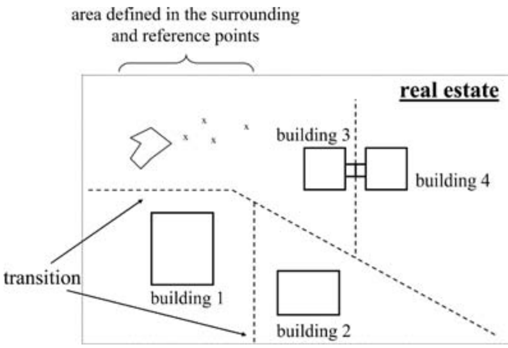

Figure 6. Transitions can connect different buildings.

Transition objects in the BIM always store the exact polygon of the transition and the identification numbers of the two BIM elements that are connected by the transition.

Figure 7 presents the structure of the Accessibility Model for a sample building expressed by a graph. The nodes represent the rooms and the edges constitute the transitions between them. The graph is undirected because of the fact that the transitions can be used in both directions. For some buildings there may be exceptions to that rule, for example some self-closing doors could be walked through only in a distinct direction without having the proper key. Multiple edges between two nodes are allowed because two rooms can be connected by more than one transition. One can change from room 4 to room 10 using either the stairs or the elevator, for example, which is also indicated by the two connecting lines between node 4 and node 10 in the graph. Windows handle the connection to the surrounding area.

The transitions t1 and t2 located in room 4 enable the transit to the adjacent rooms below and above room 4 in the cellar and in the first floor, respectively. As a consequence the BIM contains two transition objects at the same 2D-location but with different coordinates for their position above the ground and with different rooms connected. The elevator transition between room 4 and room 10 is stored twice: t2 is assigned to the ground floor and t5 is assigned to the first floor. Both are stored in the corresponding XML file. This is necessary to have the knowledge about the transition in memory, independent of the fact which of the two floor plans is currently loaded in the CADMS.

All the possible routes through the building are stored in the Accessibility Model thus describing the way of accessing certain elements of the real estate. Each route can be represented by a certain path in a mathematical graph and vice versa. It should be mentioned that the Accessibility Model is adaptable to changes in the building's structure perceived by the onsite staff. An opening in a wall can act as a new transition and a locked door or an impassable corridor makes a transition inactive. This can be interpreted as the deletion of an edge between two vertices in the graph of the building.

3.5 *Sensor model*

This category of static information stored in the BIM handles dynamic data fed into the disaster management system during the deployment. Analysing this submodel's data, incoming dynamic data can be correctly interpreted and the corresponding processes (e.g. transmission of alert messages, initiation of an evacuation) can be initiated. The type of data sources the system can retrieve information from has to be studied and well-defined. There are three main categories of dynamic data the CADMS is able to utilise.

Firstly, data from inertial measurement sensors: the route covered by rescue staff inside the building can be computed from these data. To increase the plausibility of the measurement results, elements of the building like doors and reference points are used. Therefore they could be said to belong to the sensor model. On the other hand doors and reference points also carry describing information about the building which may be displayed to the user in a context-adaptive way. For this reason these objects are logically covered by the Accessibility Model.

Secondly, data from sensors installed in the building or ad hoc placed sensors: these can be an important source of information. Fire detectors can easily locate a fire and with the use of sensors measuring the room temperature heat progression and propagation can be computed. The Sensor Model stores static information about these embedded sensor systems like their exact location, their measuring unit and their range of values under normal circumstances. Storing the identification number of a room object defined in the Accessibility Model, a sensor in the building can be logically assigned to a specified room. It can be defined which processes should be initiated if the sensor measures extreme values, like the temperature of a room exceeding the normal range. In this case the measured values influence the Accessibility Model by marking a room or the whole part of the building – depending on the measured value – as inaccessible.

Thirdly, human reported dynamic data: real-time information cannot only be originated by technical equipment, but it can also be reported by emergency staff.

The approximate temperature of a room or the location of dangerous goods are representative examples for facts collected by staff onsite. The Sensor Model stores which activities can be initiated to respond to the new situation and how the other submodels of the BIM have to be adapted to still represent the current status of the building.

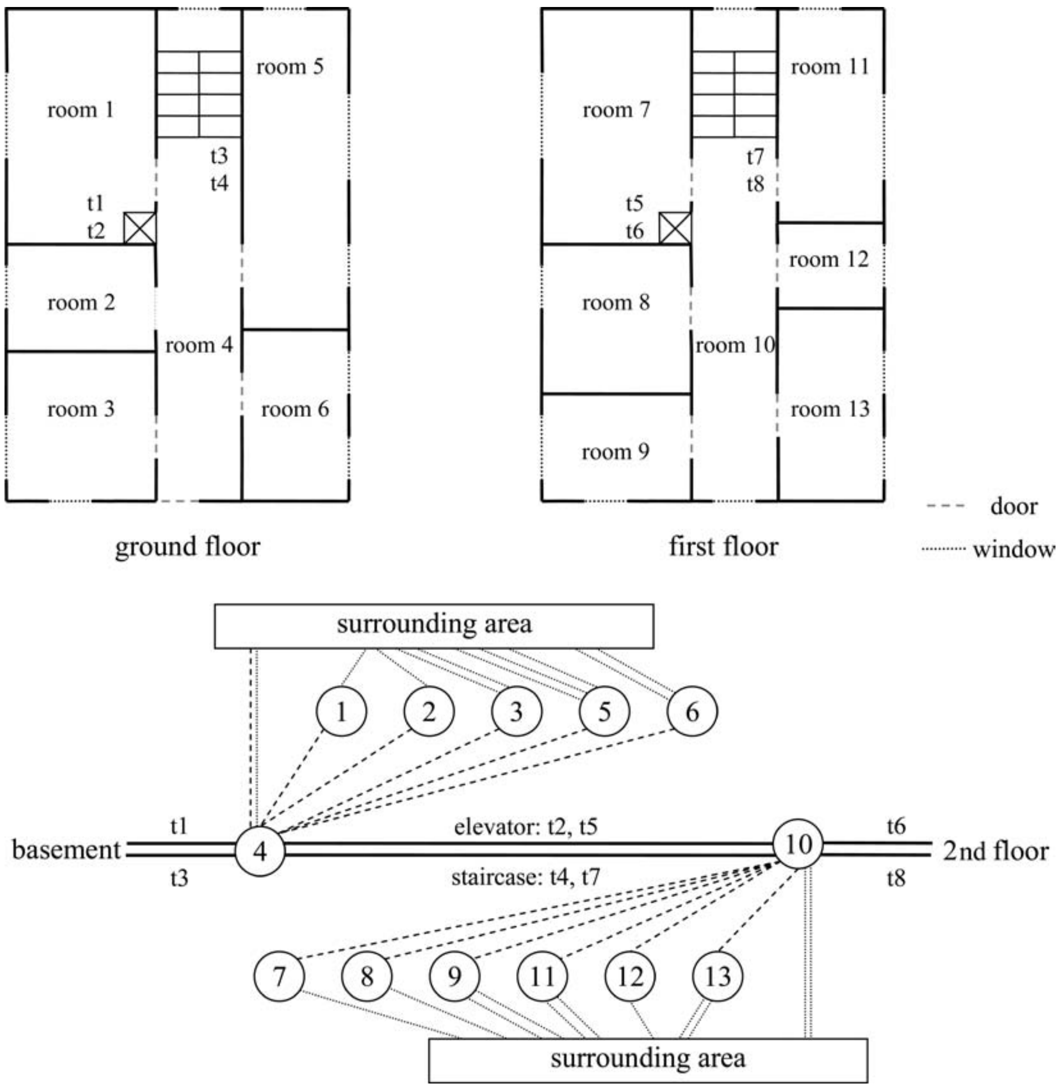

Figure 7. The building structure is represented by a graph.

3.6 *Link to the static model – Ad-hoc structural analysis*

There are techniques that allow for the creation of a structural model based on an architectural model described by the means of IFC (Deng & Chang 2006). As mentioned before, this is not suitable for the most of today's real estates since complete IFC models simply do not exist for the most of those real estates. Besides that, a direct extraction of a model for a finite element program does not function well because of the fact that there is no information about loads, load superposition and design rules stored in the architectural model.

Automatically generated finite element models are not able to completely correlate with the real load bearing behaviour.

Structural models consisting exclusively of 3D-volume elements cannot be used for the CADMS either. Such models are explained in (Romberg et al. 2004). The computations to recalculate the structural safety of a building are too complex and last too long for the mobile devices' computing power and data storage.

For these reasons the stated building information model uses a simplified static model describing sections, materials, loads and load superposition.

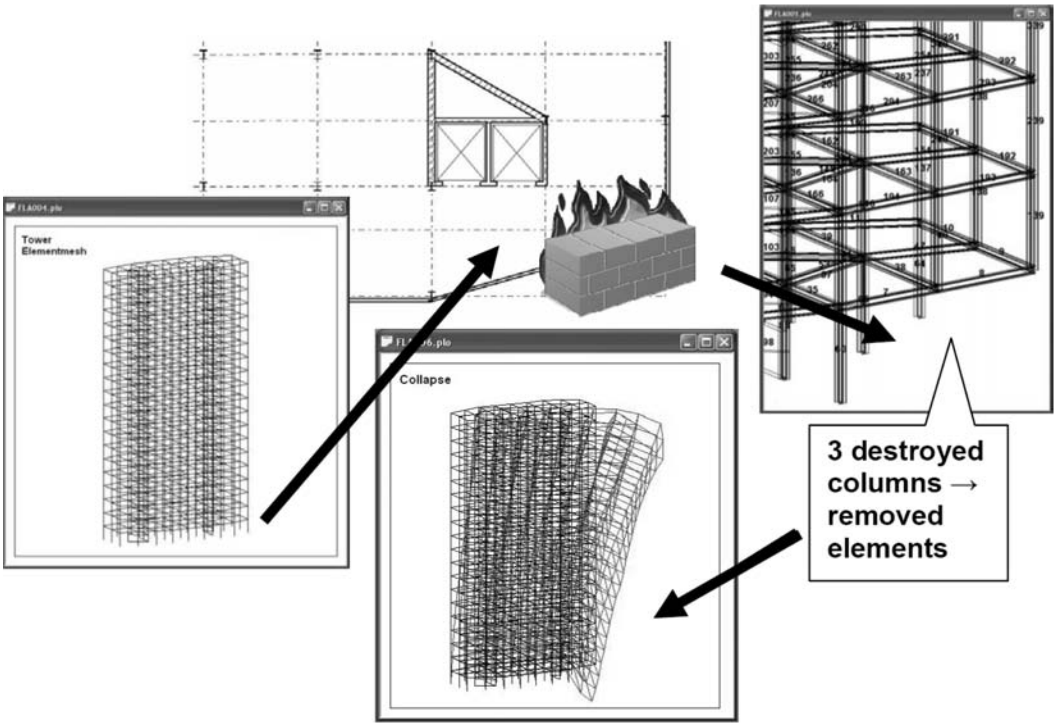

Figure 8. The ad-hoc structural analysis results in a simplified collapse model.

The structural bearing elements are modelled by the following object types: plate, shell and beam. These objects are stored in the format of a widely used finite element program. The CADMS uses the program FLASH (Walder 1979) to carry out the computations.

In the BIM the structural bearing elements are defined by their location in the floor plan and they are linked with attributes to the corresponding objects in the finite element program. By reporting the location of a collapsed bearing element, it is possible to quickly perform an ad-hoc recomputation of the structural safety with FLASH. The elements that have to be removed from its static model can easily be extracted from the BIM. Using this technique has the advantage that the members of the rescue teams do not need to be structural designers to map the observed collapsed bearing element to the corresponding elements used internally in the finite element program. The CADMS undertakes the task of preparing the input values for the finite element program.

Again, since the CADMS is based on a context-adaptive BIM, the onsite staff can be supported in choosing the correct bearing element that actually has collapsed by presenting all the objects in the BIM that might be affected and that can be seen from the user's current position in the building.

The process of initiating an ad-hoc structural analysis follows six steps from an end-user perspective:

1. Collapse of structural bearing elements
2. Observation of collapsed elements by onsite staff
3. Exact context-adaptive identification of collapsed bearing elements in the BIM
4. Extraction of the references in the BIM to the structural model in the finite element program and initiation of a recomputation
5. Analysis of the collapse model generated by the finite element program
6 Processing in the CADMS (e.g. highlighting of affected rooms, transmission of alert messages, commanding evacuation etc.): adaptation of the BIM to represent the current status of the building again and distribution of the updated parts of the BIM to the remote instances

This process is also depicted in figure 8. The user identifies the damaged bearing elements (three columns) in the CADMS, hereupon the static model can be changed and the graphical output can be analysed.

Besides the graphical module, the data transfer to FLASH can be accomplished by the use of a format

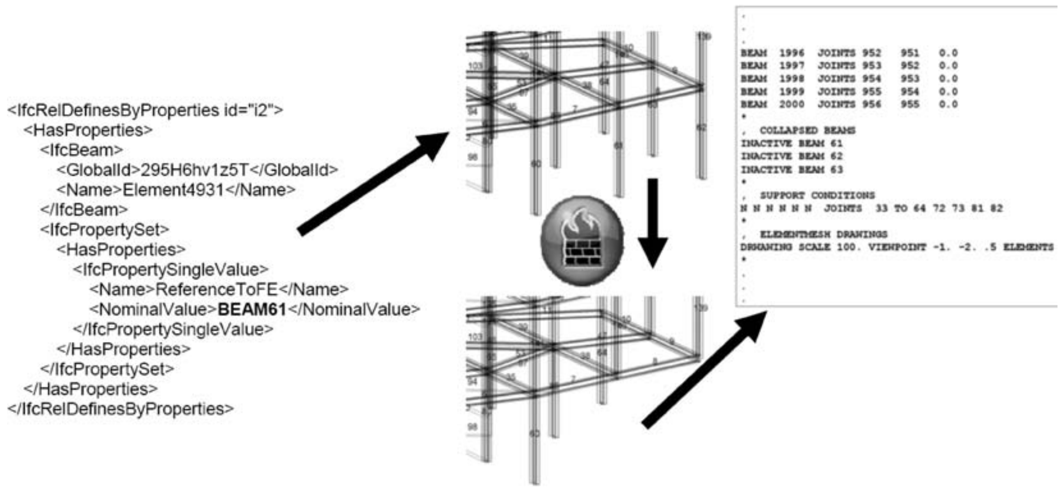

Figure 9. A beam stored in the BIM caries the reference to an entity in the finite element program.

free input language based on a principle similar to XML as well.

It would also be possible to store fragments of this input language in the BIM to automatically start the computation procedure. Any other finite element program offering a similar input language can then be used.

The textual output of the finite element program can automatically be parsed to quickly analyse the results of the recomputed structural behaviour of the building affected.

Figure 9 shows the implementation of a beam in the building information model. The attribute 'ReferenceToFE' handles the link to the entity in the structural model.

If an ad-hoc structural analysis is not desired or not possible due to a shortage of computing power of the mobile devices, the results of such calculations performed preventively before the deployment can be stored in the BIM. For technical reasons it is not possible to store the structural behaviour for all the possible combinations of bearing elements that may collapse. It is possible to define particular scenarios that have a high occurrence probability or especially far reaching consequences on the structural behaviour of the building (like an explosion in a basic elevator core) and to note at least the results of the corresponding calculations in the BIM.

It is the main goal of this part of the information model to give emergency forces a first estimate regarding the safety of damaged structures. This structural analysis need not be of high accuracy but its results have to be available fast and in a format understandable for everybody. This can be achieved by the CADMS and a connected finite element program.

4 INTEGRATING STATIC AND DYNAMIC DATA FOR INDOOR POSITIONING

To ease the navigation through buildings for emergency staff that is not acquainted with the real estate, the CADMS can highlight rooms neighbouring to the room the individuals are currently located in. Doors and transitions can be highlighted to inform about possible routes through the building.

To increase the plausibility of the sensor data generated by the IMUs the CADMS makes excessive use of the information stored in the Accessibility Model of the BIM. There are two basic methods to correct the results of position determination: manual repositioning and automatic repositioning. Using the first technique user interaction with the CADMS is necessary, while the latter does not need the help of the user operating the system.

4.1 *Manual repositioning*

Integrating the acceleration data provided by the IMUs twice yields the distance a person has covered. To map this distance to a route in the building a starting point has to be defined. Reference points stored in the Accessibility Model serve as these starting points necessary to initialise the process of indoor positioning.

Since the plain measurement results start lacking accuracy with time, repositioning is needed. In this case the user can communicate his position relative to a reference point to the CADMS. In practice he heads for a location in the building that is described as a reference point in the BIM. He reports the object that he is close to to the system, which supports him by highlighting all the reference-points in his current

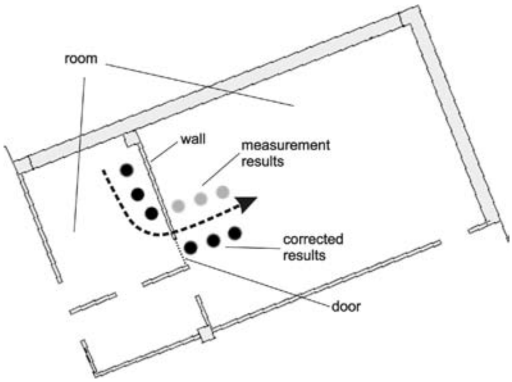

Figure 10. The position is corrected by making use of well-defined transitions.

surrounding in a context-adaptive manner. After identifying the correct object on the head mounted display, the user reports his position relative to the object by choosing the right position out of a number of possible positions offered by the CADMS. After that, the coordinates of the user can be adapted in correlation with the coordinates of the reference point.

Due to the architecture of the building well-defined reference points may not always be available when a user wants to adjust his position or the explained repositioning procedure may last too long under certain circumstances. Manual repositioning can also work without using reference points.

The rescue worker can give short remarks about his current location. By calling the system command 'next room' he can indicate that he has already entered another room although the CADMS still assumes him to be in the same room as before. The system can calculate the distances between the assumed position and all the transitions to other rooms. The measurement error is expected to be small so the displayed position is adapted to appear in the room with the shortest distance. If this is not correct, the user can report this fact by using other concise commands to adjust the position to the room with the second shortest distance.

This principle of manually correcting the results of indoor positioning can be applied for other types of transitions in the real estate as well.

4.2 *Automatic repositioning*

Exploiting the information covered by the Accessibility Model the position displayed on the head mounted display can be corrected without interacting with the system.

One example for a technique for repositioning automatically is presented in figure 10. A floor plan consisting of three rooms is shown. On his way through the building the user leaves a room and enters another room, which is indicated by the arrow. His time discrete positions in the new room detected by the CADMS are drawn in grey colour. The assumed route intersects a wall which is represented by room polygons. Taking into account that the transition takes place close to a door the grey positions can be shifted towards the door. Only the corrected results are presented to the user. In the case that the user is not satisfied with the result yielded by the automatic repositioning process he can adapt the position on his head mounted display manually again.

If the detected path intersects a wall far away from a door the assumed position can be 'pulled back' into the room the user is currently located in until he indicates that he has entered another room or he uses other methods of manual repositioning.

Repositioning automatically can also be based on the stored information about stairs, ramps, ladders and so on.

5 CONCLUSION AND OUTLOOK

Effective disaster management offering indoor positioning and context-adaptive displaying of building information is extremely important in the case of an incident. Currently there is no functioning system on the market (Glanzer et al. 2007).

To improve the accuracy of indoor positioning, static data stored in a building information model and dynamic real-time data are combined. This is a very promising approach showing a lot of potential. The suggested BIM contains many provisions to store heterogeneous information. A tradeoff between the time consuming modelling of real estates and a high positioning accuracy has to be made. In this context already existing CAFM data can be beneficially utilised.

It turns out that the combination of static data stored in the BIM, sensor data and human reported data offer many possibilities to introduce and improve indoor navigation, ad-hoc structural analysis of buildings and the interaction with sensors installed in the building.

The refinement of the algorithms to automatically correct the user's position is scheduled for the near future. The optimisation of the interface to the user is another important task. Tests of the user interface during regular fire practice will be conducted.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Spaces meet users in virtual reality

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ABSTRACT: In this paper, we present outcomes from Finnish HospiTool project that introduces an interactive user-oriented approach to health facility planning, construction and renovation. Tools were developed that enable end user participation in the planning through evaluation of hospital spaces in order to match the spaces with user needs and requirements. The plans were first presented by making use of new visualization technologies. Solution for 3D model embodies two virtual reality environments – Computer Aided Virtual Environment (CAVE) and in VTT's Lumeviewer, a lightweight visualization client for personal computers. Then the user feedback was developed to be user requirements in EcoProP systematic requirements management tool. The feedback from Virtual reality was also compared to interviews in existing hospitals. Evidence Based Design (EBD) has considered in this research.

1 INTRODUCTION

The project started after a roadmap that clearly showed a need to take end-user opinions into account as early as possible when designing hospitals and its processes. Also tool supporting decision-making was as well among money decision makers as well among other stakeholders involved in planning spaces and processes.

In conventional design process the goal of a designer is to satisfy paying client. In other words, the designers take into account owner perception and match end-user needs complied with orders from authorities. Therefore, relatively clear relationship exists between designers and paying clients, but this can leave important gaps in understanding between the clients and the end-users and between the designers and users (Barrett and Stanley 1999, page 60). Regarding this gap, bulk of the research in construction industry is allocated to design process but true interaction towards end-users has remained as a rather unexplored research domain.

User-centric approach has gained more emphasis in the academia during the last decades. Especially in hospital environments, user feedback has indicated that physical environment has a lot to be improved to be a healing environment for patients and a motivating work place to staff.

Great potential exists in user-centric approach. In Finnish hospitals the experiences have showed that three-year period of hospital use equals facility construction costs. Therefore, it is justified to argue that end-user viewpoint should be recognized comprehensively in the design process.

User-Oriented Hospital Space (HospiTool) project is a joint project by the Technical Research Centre of Finland (VTT) and the National Research and Development Centre for Welfare and Health (STAKES). A parallel project is run by Finpro. The project involves the hospital districts of Southwest Finland and South Ostrobothnia, and currently also three companies: Abloy Oy, Väinö Korpinen Oy and Pöyry CM Oy. In addition, the project is also closely connected to educative purposes, and collaborates with North Karelia university in Seinäjoki and Turku University of Applied Sciences.

Project is carried out within FinnWell program of Tekes (Finnish Funding agency for Technology and Innovation). The program lasts until end of year 2008, and has an emerging objective to developing operational processes of healthcare. There is clearly a need to take end-user opinions into account as early as possible when designing hospitals to support better the related processes.

2 OBJECTIVE

How well do spaces support processes within the spaces like patient room in hospital? We have explored

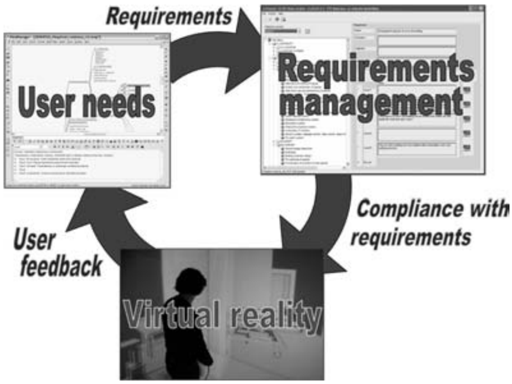

Figure 1. Research approach consisting from capturing user needs, managing user requirements and evaluating compliance of requirements in virtual reality.

answers to earlier question in HospiTool project. We started to find new concepts for end-user participation using state of the art visualization technology, virtual reality (VR), and compare created virtual model to real environment experiences through interviews. We have developed virtual reality solution from three-dimensional architectural information. Solution provides as natural as possible feeling for communication process with end-users.

3 APPROACH AND METHODS

This paper introduces an interactive user-oriented approach to health facility planning, construction and renovation. The results are outcomes from HospiTool project, where tools were developed that enabled end-user participation in the planning and evaluation of hospital spaces in order to match the spaces with user needs. Then, user needs were formulated to user requirements and outcomes have been managed in VTT's EcoProP software for systematic requirements management (Fig 1). Defined set of user requirements were evaluated in virtual reality by making use of new visualization technologies.

We used EcoProP software to capture the requirements systematically. Software is designed for developers, owners and consultants, to help capture needs at the early stage of project. Typically tool is utilized in team sessions for developing common targets to design team. EcoProP comprises standalone application to database, and provides an easy-to-use user interface to information. It can be used for both new construction and renovation projects, and also for benchmarking purposes.

Realistic surface materials and lighting were simulated using texture mapping and radiosity methods. This was done to catch the most natural feeling in the

Figure 2. View from patient tool in CAVE.

3D model. The developed 3D model was used both in the Computer Aided Virtual Environment (CAVE), see Fig 2, and in VTT's Lumeviewer.

The CAVE was in the facilities of the School of Information and Communication Technology at the Seinäjoki University of Applied Sciences (SeAMK).

The CAVE is based on a cluster of computers. It had five rear-projected walls in a cubic arrangement, covering the user's entire field of view. Digital light processing (DLP) projectors were used to display a stereo image on each wall, giving a three-dimensional view through shutter glasses. The user was tracked by the Flock of Birds magnetic tracking system from Ascension Technology, allowing them to move around in the model (within the physical bounds of the CAVE room). In addition to this, a joystick-like wand could be used for moving longer distances.

The Lumeviewer is 3d "lightweight 3D visualization Client" for personal computers developed in VTT (Rönkkö and Markkanen, 2007). The software is coded on the top of the OSG (open scene graph) core, and system consists of pc with dual graphics card, stereo projector, shutter glasses with IR synchronization and a semi-transparent screen. When person stands about 1 m away of the screen, the view is almost 1:1 scale trough shutter glasses (Fig 3).

Six patients from a rehabilitation ward and an acute ward of the Health Centre of Seinäjoki and from a neurological rehabilitation ward of the Seinäjoki Central Hospital were interviewed in the CAVE. They were aged from 56 to 83 years (mean age being 76 years). Four of them were women and two men. Patients were selected by nurses of those wards to ensure that they would be fit enough and capable to communicate in a new environment.

Also six nurses were interviewed in the CAVE. Their mean age was 38 years. They were all women. Most of them had work experience of nearly 20 years, only one had been working in hospitals three years (average 10 years).

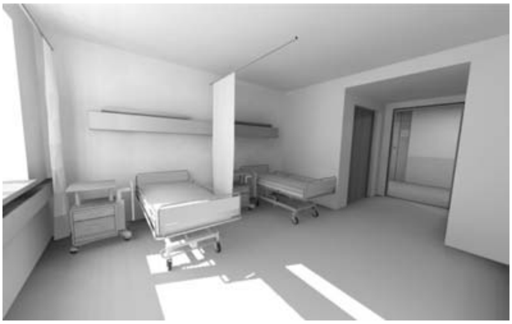

Figure 3. Rendered 3D view from screen view in Lumeviewer.

Figure 4. The Patient interview in the CAVE.

4 USERS VISIT THE VIRTUAL REALITY

The term Virtual Reality is used to describe applications in which we can interact with spatial data in real-time (Whyte 2002, page 3). VR is an experience in which a person is "surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it (Cruz-Neira et al. 1993). However, in the design process it is important to distinct the term from structural building models, such as models developed with CAD tools, containing also parametric information about the actual building components.

Virtual Reality, as a medium, has three defining characteristics: it is interactive and users can interact with models, the models are represented in three spatial dimensions, and feedback from actions is given in real-time (Whyte 2002, page 3). Systems are supporting this interactive, spatial, real-time medium with the computer hardware and software through interaction devices. At high level those systems may be classified as immersive, non-immersive and augmenter reality systems (Whyte 2002, page 4).

We used CAVE based virtual reality for user visits, nurses and patients, together with a designer or an interviewer. The nurses performed a detailed walk-through in 4 different patient room concepts and discussed with a hospital design nurse (Fig 4).

The discussions with nurses focused both work processes and space related matters. The visit took typically about one hour. Only a few nurses did have mild simulator sickness day after the session.

The Patients were in this case very old, almost all of them sitting on a wheel chair or ordinary chair during the visit. The pre design interview was done by social psychologist repeating the same pattern every time. Because the age (about 80 years median) of the patients in the interview was high, psychologist was prepared to stop in case patient request. Only one of the interviewed patients was not visiting all of the 4 rooms. Most of the patients were happily commenting the virtual rooms like being in one even trying to "knock on the table".

5 REQUIREMENTS MANAGEMENT

Descriptions of technical solutions are currently guiding the design phase and space layout is often fixed too early in many cases. Architects first space layout proposal often leads to alternative design solutions whereas they should be inherited from activities taking place in the building, especially in hospitals. Therefore, aforementioned process ends up to lost value for user, although turnover improves when customer expectations are fulfilled (Lindkvist 1996; Smith et al. 1998).

Requirements management tools aim to provide applicable and updatable information for following project phases. In order to attain this, the user requirements need to be captured as a first target of requirements management. Since it is impossible to satisfy all needs of all stakeholders for various reasons, the second target is putting the separate user requirements together. Compliance of design with the requirements should be verified constantly during the project, in particular to eliminate contradicting requirements. It is difficult to judge the relative importance between the requirements. The last target of requirements management is to ensure that results lead to desired results.

One of the drivers for the performance approach implementation in Finland has been EcoProP software in Fig 5 (EcoProP 2008). Tool is used to create design brief that includes set of objectives how the building should perform in use – defined as requirements. Theoretical framework in EcoProP software leans on hierarchical management of requirements. Individual requirements are described with the help of five pre-set target levels that can be expanded to cover also comments from design session where requirements are set.

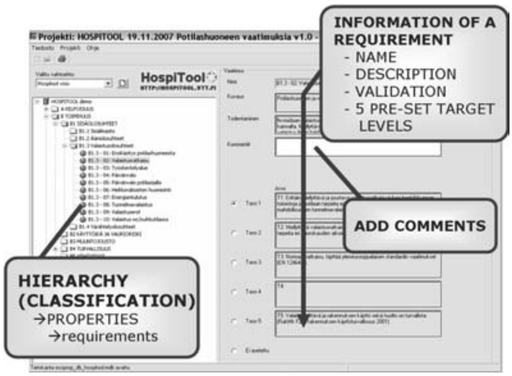

Figure 5. User Interface of EcoProP systematic requirements management tool.

System also has functionalities to evaluate rough life-cycle costs (LCC), and corresponding life-cycle analysis (LCA) impacts, based on requirement levels between to support decision making. Further, it is also possible to perform alternative design comparisons to compare various design options.

6 INTERVIEWS RESULTS IN VIRTUAL REALITY

During the interviews, patients were asked to express their opinion as freely as possible on following features of the patient rooms in the CAVE environment: colours, lighting, furnishing, surface materials, room size, placement of windows, and pleasantness, aesthetics and functionality of the room in general. They were also asked if they would like to change anything in the environment.

In the end of the interview the patients were asked how they felt about being in the CAVE, how real the experience of being inside a patient room or bathroom was, and did they have any unpleasant feelings whilst being inside the CAVE. The interviews were recorded and videotaped and analysed using Atlas.ti -programme.

Following subjects were discussed by patients in the CAVE:

- colours
- windows
- surface materials
- other patients (good company)
- furniture, paintings, TV etc. (size, form, placement)
- room size.

A few subjects were NOT discussed in the CAVE though they were discussed in the parallel study performed in the three wards. These subjects include:

- air conditioning
- temperature
- noise
- height of the thresholds
- thickness of the grab bars in bathrooms

The reason was that these issues did not 'exist' in the CAVE environment or they were stable. Interesting is that one of the patients reckoned that thicker grab bars would have been better in the bathroom, although it was not possible to feel the thickness. Another patient tried with his feet if the floor was slippery. A few of the patients found it difficult to evaluate the size of the room or to compare one room to another room.

It might not be possible to evaluate perfectly issues relating to room size, furniture and moving in the CAVE but on the basis of respondents' behaviour it can be estimated that the CAVE produced a strong illusion of being inside a modelled room. Clearly it was much easier for them to express their opinions during a visit in the CAVE than on the basis of reading documents such as architectural drawings.

Generally, all respondents expressed either that evaluating rooms in the CAVE was a positive experience or that at least it was not a negative experience.

7 DISCUSSION

Making use of virtual environments gives a possibility to provide planners and designers with increased understanding of user experiences. Systematic requirements management is enhanced by true dialogue and it is relatively easy to produce and compare various design options in an early planning phase.

The HospiTool process was successful in creating a platform for development of user-driven innovations in the operating environment: process innovations for healthcare and product innovations for industry. Ultimately, the main objective is to develop a generic concept for inclusive design: to make spaces support processes within the spaces. The evidence based design (EBD) is also taken into consideration in the concept.

Conventional construction process is mainly production driven although buildings should be made for users. Requirements management is targeted to increase products value. It's obvious that human and organizational questions need more attention than technical aspects with the analysis of client's needs (Lindkvist 1996). Open and transparent communication amongst the parties involved is emphasized.

Construction and real estate industry is currently experiencing a paradigm change towards increased use of Information Technology. Building Information Modeling (BIM), that is one of the drives of the aforementioned paradigm change, is an approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in a digital format. Further, this paradigm change is also an enabler for the next step that involves also taking users into the design process as active participants.

During last decades Evidence Based Design has challenged the conventional hospital design arguing that by improving physical environment hospital facilities would be healing environment for patients, better places to work for staff and attractive environments to visitors supporting patients to heal. Much of the EBD research is covering issues reducing stress induced by poor environment such as lack of natural light, lack of positive distractions and noise.

Especially the issues tested by interviewing patients in CAVE have been often rejected in conventional hospital design. Thus the findings of this research support the importance of development of methods for user involvement in hospital design process. Many of those features are not possible to experience through traditional design methods and processes. The CAVE environment is a useful tool for feedback from users and there is a great need for developing it further.

The project has already been creating a real feedback from end-users (both nurses and patients) to the new hospital building which is in the planning phase. The further project is starting and it is planned to support one hospital planning only. The different stakeholders (architect, bathrooms deliverer, door deliver etc) are participating the project as well as planning it.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

User interfaces for building systems control: From requirements to prototype

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ABSTRACT: Occupant control actions in a building (i.e. user interactions with environmental systems for heating, cooling, ventilation, lighting, etc.) can significantly affect both indoor climate in and the environmental performance of buildings. Nonetheless, relatively few systematic (long-term and high-resolution) efforts have been made to observe and analyze the means and patterns of such user-system interactions with building systems. Specifically, the necessary requirements for the design and testing of hardware and software systems for user-system interfaces have not been formulated in a rigorous and reliable manner. This paper includes an exploration of the requirements of interfaces for user-systems interactions in sentient buildings. The outcome of this effort serves as a starting point for developing a new generation of user interface products to promote higher levels of connectivity between occupants and sentient environments.

1 INTRODUCTION

Based on advancements in information technology in recent years, new possibilities have emerged to better connect the occupants with environmental systems of buildings. Particularly in large and technologically sophisticated buildings, multi-faceted interactions between building occupants and the multitude of environmental control devices and systems need to be tightly integrated in order to assure effective building operation and performance. As to the role of user interfaces in the context of intelligent built environments, there are a number of precedents. For example, the ubiquitous communicator – the user interface of PAPI intelligent house in Japan – is developed as a communication device that enables the occupants to communicate with people, physical objects, and places (Sakamura 2005). More recent works on the integration of user interfaces into intelligent environments include Swiss house project in Harvard University (Huang & Waldvogel 2004), and Interactive space project by SONY (Rekimoto 2007).

This paper explores the requirements and functionalities of user interfaces for sentient environments. “Sentience” denotes here the presence of a kind of computational second-order mapping (or meta-mapping) in building systems operation. This requires that the flow of raw information collected around and in a building is supplied to a building’s continuously self-updating model of its own constitution and states (Mahdavi 2005). Thus, a sentient building may be defined as one that possesses a multi-faceted internal representation of its own context, structure, components, systems, and processes. It can use this representation, amongst other things, toward the full or partial self-regulatory determination of its indoor-environment status (Mahdavi 2004). Given this view of building sentience, we explore in this paper the requirements of an adequate user interface system to facilitate effective communication and interaction between building occupants and environmental systems. We first discuss the results of previous research concerning the comparative evaluation of market products (interfaces) for user-based control of building systems. We then introduce a set of user requirements toward design of new user interface products for sentient environments. Such new developments are expected to achieve new levels of connectivity between occupants and the environmental systems for indoor environmental controls in buildings.

2 BACKGROUND

2.1 *Previous research*

In a previous research effort (Chien & Mahdavi 2007), we compared twelve commercial user-interface products (see Table 1) for building control systems. These products were classified as follows: A type (“physical” devices), B type (control panels), and C type (web-based interfaces). Thereby, we considered three dimensions, namely control options, information types, and hardware. The results were arranged in terms of: *i*) comparison matrices of the selected products based on three dimensions (information types, control options,

Table 1. Overview of the selected products.

Product type	Product	Company	Illustration	Code
A Type: Physical devices	Circle point	Zumtobel		A1
	Uniqa Control Point	Johnson controls		A2
	LONVCU	Warema		A3
	CM900	Honeywell		A4
B Type: Control panels	Emotion	Zumtobel		B1
	Companion-8	Convergent Living		B2
	OmniTouch	Home Automation		B3
	DDC4000	Kieback & Peter		B4
C Type: Web-	Uniqa web-interface	Johnson controls		C1
based	iSkin	Zumtobel		C2
interfaces	Serve@ Home	Warema & Siemens		C3
	merten@ home	Merten		C4

and hardware), and *ii)* product comparison/evaluations by the authors' based on seven criteria (functional coverage, environmental information feedback, intuitiveness, mobility, network, input, and output).

Subsequently, we conducted an experiment, in which forty participants examined and evaluated a subset of the above user interfaces for buildings' control systems, mainly in view of three evaluative categories (first impressions, user interface layout design, and ease of learning).

Comparison results of the selected user interface products for intelligent environments warrant certain conclusions regarding their features and limitations. Interfacing with radically new kinds of environments that involve sentient technologies may require rethinking the occupants' requirements and attitudes. In addition, new interfaces encounter problems associated with numerous new technologies simultaneously embedded into a sentient building. Thus, to arrive at effective and comprehensive user interface models for sentient buildings, it is not only necessary to better understand the features and strengths of the available solutions, but also to anticipate and avoid negative consequences of interface technology integration in this critical domain. In the following, we briefly discuss certain areas of deficiency in the status quo and consider possible remedies.

2.2 *Control options and functional coverage*

In sentient environments, one key point is how the occupants interact with the multitude of environmental control devices and how they deal with the associated information loads (technical instructions, interdependence of environmental systems and their aggregate effects on indoor conditions) in an effective and convenient manner. The result of the above mentioned study implies that limited functional coverage and intuitiveness of use often correlate. This suggests that an overall high functional coverage may impose a large cognitive load on (new) users.

2.3 *Provision of information*

If it is true, that more informed occupants would make better control decisions, then user interfaces for sentient buildings should provide appropriate and well-structured information to the users regarding outdoor and indoor environmental conditions as well as regarding the state of relevant control devices. Most B and C type products in our study provide the users with some information such as the state of the devices. However, they do not sufficiently inform the occupants regarding indoor and outdoor environmental conditions. This implies that the occupants are expected to modulate the environment with the condition of insufficient information

2.4 *Mobility and re-configurability*

The hardware dimension addresses two issues, namely, *i*)mobility: user interfaces with spatially fixed locations versus mobile interfaces; and *ii)* re-configurability: the possibility to technologically upgrade a user interface without replacing the hardware may decrease the cost of rapid obsolescence of technology protocols. C-type terminals such as

PDA and laptops that are connected to controllers via internet, facilitate mobility. In contrast, Type A and B products are typically wall-mounted and thus less mobile. As far as re-configurability is concerned, the user interface software may be easily upgraded in Type B and C products, whereas the conventional A-type products are software-wise rather difficult to upgrade.

2.5 *Input and output*

Certain type-B and type-C products provide the users with richer manipulation possibilities that – if transparent to the user – could support them in performing a control task. There are other products (particularly type-A), however, that are rather restricted in presenting to the users clearly and comprehensively the potentially available manipulation and control space. Nonetheless, as our results suggest, type-A products are more positively evaluated than the more modern/high-tech (type-B and C) products, especially in view of first impressions and ease of learning. Here, we see a challenge: modern (high-tech) interface products that offer high functional coverage, must also pay attention to the cognitive user requirements so that formulation and execution of control commands are not overtly complicated.

2.6 *Additional observations*

In addition to the quantitative processing of the feedback provided by the forty participants in the above mentioned experiment, we also considered a number of their individual statements (open-end comments) regarding the interface products tested. Thereby, we specifically focus on cognitive problems in navigation.

i) Organizational layout: In our experiment with the participants, we were interested to know if the existence of a clear organizational layout of the interface was important to them. Their comments suggest that a well-organized layout may effectively guide the users in task manipulation and facilitate, thus, interactions between users and control devices.

ii) Shortcuts and repetition: A scene function provides the possibility to define multiple set points for multiple environmental parameters simultaneously. Thus, proper combination of such set points can be pre-programmed in conjunction with typical use scenarios. Scene functions thus offer participants shortcuts to simplify the execution of repetitive (and often time consuming, dull and error prone) tasks.

iii) Clarity of terms and icons: The labels (i.e. iconic buttons, tags, and text items) play an important role in how navigation proceeds. Thus, such labels should be plainly worded and clearly visualized. They must be simple and easy to understand. Otherwise, as certain comments imply, frustration may result particularly in the earlier phases of interface usage, as the users are not fully familiar with the product.

iv) Navigation memory: By their nature, conventional physical devices for communication appear to provide more simple options for the users to operate systems due to their limited (one-level) depth. The other products require, in contrast, moving from one "page" (level) to the other. Many participants felt that some products require too many jumps in navigation, whereby each screen substantially differed from the other. This may make learning and retaining of the required manipulation sequence difficult. A smaller number of transitions amongst screens seem to be preferred by most participants. The participants' comments imply that limited functional coverage and navigational ease often correlate. This suggests that an overall high functional coverage can impose a larger cognitive burden especially on new users. Interface design must thus pay particular attention to supporting cognitively friendly use patterns while offering richness in manipulation options.

3 ONGOING DEVELOPMENT

Previous research in the analysis of product comparison and interviews highlighted a number of basic principles and expectations regarding the design of desirable user interface products for sentient environments. Starting from these results, we will make an attempt in this section to further articulate user requirements toward actual design of such interface products.

3.1 *Defining posture*

Posture is a way of talking about how much attention a user will devote to interacting with a product, and how the product's behaviors respond to the kind of attention a user will be devoting to it (Cooper et al. 2007). According to our previous research (Mahdavi 2007, Chien & Mahdavi 2007), we concluded that the essential feature of the indoor climate control user interface is its short-term usage patterns. This kind of user interfaces with a transient posture must offer very short-term manipulation possibilities. They must efficiently offer important and frequently needed functionalities and the appropriate accompanying requisite information, and then quickly step to background, letting the occupants continue their normal activities (such as working on paper-based and screen-based tasks in offices).

3.2 *User models and expectations*

User models are synthesized from our previous data obtained from 40 interviewees in order to better clarify the design implications of different user requirements. These models are composite prototypes, by assembling related user patterns across individuals with similar characters. Thereby, we specifically considered two user models (primary model with its extension and secondary model) as our human target.

3.2.1 *Primary model and extensions*

In this type of model, the users always have a great amount of workload (e.g. paper/screen tasks) that monopolize their attention for long periods of time while working. They tend to have certain organizational and time-saving techniques to structure the course of their working day. Despite the factual importance of the interface for the users' daily activities and conditions, users of a primary interface model are willing only to dedicate a very limited time-budget to learn it. Rather than attempting to load extensive functionalities into a primary user interface product, it must be designed such that it is perceived as being simple and easy to use. The users in a primary user interface model scenario, expects the least possible time (minimum navigation) to complete a certain control action and to immediately return to their office activities. Thus, the most frequently needed control options and corresponding required information must be identified and offered in a primary user interface model. In this case, additional options/information may be expected to disturb the users. Primary model may be further augmented in terms of an extended version with additional (yet non-extensive) options and information features (e.g. indoor/outdoor environment conditions).

3.2.2 *Secondary model*

The human targets of the secondary interface models might have as much as a working load as those of the primary interface models, but they value more a sense of control over their environment and the associated devices and tools. Thus, they are more willing to allocate time and patience to manipulate their control user interfaces and to deal with rather complicated settings and details. Likewise, they would be open to and interested in acquiring more information about their environmental conditions and means and ways of controlling their workplaces. As a result, a secondary user interface model needs to be more detailed and versatile. It must provide the users with much more options and information than primary models, as the secondary model users can be expected to master all kinds of control options, assign/modify their customized scenes, and acquire multiple categories of indoor/outdoor information.

3.3 *Requirement profiles*

We generated a set of requirement profiles arranged in accordance with the previously described dimensions, namely information types (see Table 2), control options (see Table 3) and hardware (see Table 4). In this context, a desirable user interface product may serve both user models mentioned above. Moreover, it can embody the integration of the functionalities associated with these two user groups.

Table 2. The requirements for the information types dimension.

			User Types		
			Primary		
CODE of classification			B*	E**	Secondary
Info Types	General Info	Date/ Time	•	•	•
	Indoor Info	Temperature	•	•	•
		Humidity	—	•	•
		Air Velocity	—	—	•
		Carbon Dioxide	—	—	•
		Illumination	—	•	•
	Outdoor Info	General Weather conditions	•	•	•
		Temperature	•	•	•
		Humidity	—	•	•
		Wind Speed	—	—	•
		Wind Direction	—	—	•
		Global Irradiance	—	—	•
	Device Status	HVAC System	•	•	•
		De-/ Humidification System	—	•	•
		Windows	—	—	•
		Blinds	—	—	•
		Ambient Lighting System	—	•	•
		Task Lighting	—	—	•

(* Basic; ** Extended)

3.4 *Prototyping cycles*

In order to transform user requirements to concrete designs, initial prototyping (i.e. generation of user interface mock-ups) is being currently conducted following a scenario-based design and focus group method (Carroll 1995). To provide an illustrative example of the initial results, Figure 1 provides a screenshot of a user interface prototype for the test cells of our Building Automation Laboratory (Department of Building Physics and Building Ecology, Vienna University of Technology). The layout design and navigation structure are being developed based on the above mentioned requirement profiles and design principles.

Table 3. The requirements for the Control Options dimension.

CODE of classification			User Types: Primary B*	User Types: Primary E**	User Types: Secondary
Control Options/ Extensions	Control via device	HVAC System	•	•	•
		De-/ Humidification System	—	•	•
		Windows	•	•	•
		Blinds	•	•	•
		Ambient Lighting	•	•	•
		Task Lighting System	•	•	•
	Control via Parameters	Air Movement (path)	—	—	•
		Air Change Rate (h^{-1})	—	—	•
		Temperature (° or ¢K)	•	•	•
		Ambient Illuminance (lx or %)	•	•	•
		Task Illuminance (lx or %)	•	•	•
		Humidity (%)	—	•	•
	Control via perceptual values	Warm/Cool	•	•	•
		Brighten/Dim	•	•	•
		Humidify/Dry	—	•	•
		Ventilate (Air Flow)	—	•	•
	Control via scenes	Entering	•	•	•
		Leaving	•	•	•
		Screen Task	•	•	•
		Paper Task	—	—	•
		Meeting	—	•	•
		Presentation	—	—	•
		Break	—	—	•
		Energy Saving	—	•	•
		Cleaning	—	—	•
		All lights on	—	—	•
		All lights off	—	—	•
		Lights default	—	—	•
		User-based Scenes	—	•	•
	Control via Schedule		—	•	•
	Control via micro-zoning		—	—	•

(* Basic; ** Extended)

4 CONCLUSION

While the present paper does not offer a detailed final design for desirable user interfaces for future sentient environments, the user requirements for developing such interfaces have been formulated. The user requirements embody the user models and a set of dimensions for product specification involving information types, control options, and hardware. Moreover, Initial prototyping cycles are being conducted leading to preliminary user interface mock-ups. These early prototypes will be tested and refined toward mature future interface products toward achieving desirable indoor climate conditions while meeting the objectives of a sustainable building operation regime.

Table 4. The requirements for the hardware dimension.

Aspect	Requirement
Input	Users may input their data and commands via mouse, keyboard and touch panel (12 inches plus recommended for secondary level)
Output	Users are provided with data via LCD screen and Touch panel (12 inches plus recommended for secondary level)
Mobility	Primary level could be realized both spatially fixed and mobile interfaces. Secondary level should be rather realized in desktop terminals for long-term detailed manipulation
Network function	Users may access all resolution levels (basic, extended, secondary) via internet
Reconfigurability	All interface types must be technologically upgradable without replacing the hardware

Figure 1. Sample screenshot of early interface prototype for test cells of the Building Automation Laboratory.

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Non-intrusive sensing for PDA-based assistance of elderly persons

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ABSTRACT: Improvement of quality of life is an important component linked to healthy environments. The increasing proportion of aged people in population of developed countries poses the need of providing assistance services based on a continuous monitoring far from hospital or residential institutions. Non-intrusive sensors allow obtain active, constant and real-time information relative to health characteristics in a smart way. The identification of critical values for parameters linked to different sensors provide a support for a fast intervention which minimizes risks linked to delays or lack of conscience. Prevention intends to improve the quality of life for persons with cardio-respiratory problems, by means of a monitoring compatible with mobility.

1 INTRODUCTION

Embedded wireless devices are being developed for multiple purposes with an increasing list of applicability domains. Some factors which are contributing to this increasing are linked to the ubiquity of wireless communications and processing systems in networked system infrastructures. The software architecture design is common to different kinds of product lines in e-and m-business. Nevertheless, in this work we shall restrict ourselves to illustrate such software architecture with a design and implementation focused towards Telemedicine services based in a Point of Care (POC) information. The main goal of Telemedicine is to improve the patient quality of care. Telemedicine services can be relative to closed environments (home, ambulatory or hospital care) or open environments (on-site trauma, long-term care).

An efficient design of basic software architecture provides the support for a large range of applications involving e-business and e-health, between other. It is necessary to enable ICT for improving their performance and the trust for the next generation of electronic mobile devices and to avoid the collapse of health insurance and national health care systems in the next future. Main required functionalities are very similar between them, no matter the application domain or environment characteristics. Even in Health Care Centers (wired Internet solutions), patients and medical staff are moving, and information must be available anytime and anywhere. In this way, it is possible to take decisions in real time, by avoiding the delay corresponding to development cycles. Thus, it is natural to paid a special attention to personalized solutions based in mobile devices, such as a Personal Data Assistant (PDA) as smart device for collecting, processing and transferring information.

The raising of life expectancy and the increasing of aged people in most OECD countries poses some challenges for improving the quality of services related to health risks and reducing costs in the healthcare systems. Mobility linked to a better quality of life of aged people, can need a monitoring under medical supervision in networked environments. A supervised self-management of patients is becoming one of the most important challenges for the next future in mobile health care and Telemedicine. This article is focused towards the design and implementation of a Services Oriented Architecture (SOA) for Health Care of aged people.

Some improvements of SOA applied to health care involve to a trust of aged persons regarding remote assistance, time saving systems for the medical staff making recommendations in presence of abnormal behaviour of parameters quicker response in crisis or emergences. Life expectancy require to paid an increasing attention not only to population ageing disability, but to new degenerative disorders whose effects must be bounded to preserve the quality of life, and consequently the social benefits for increasing portions of population. Furthermore, the unhealthy lifestyle of large portions of middle-aged and young people is increasing the risk of chronic diseases for persons requiring a closer monitoring.

The close network between innovative technology suppliers, extensive assistance and potential customers in most of European countries, provides a structural support for new lines of products with high added value and socio-economic impact in health care systems. The challenge for ICT is how to provide a support for Telemedicine and m-services in larger environments, with a special attention to autonomous persons which are living far from a health center (gate-keeping systems. Most of already available products are focused towards emergencies management. Thus, it is necessary to try of developing active real-time monitoring devices and local mobile services focused towards preventive surveillance in Telemedicine. The monitoring is based in minimally intrusive sensors able of early detecting risk situations, in order to minimize the response time to the intervention from Health Care systems. In this way, we hope to improve the quality of life and independence of risk patients or elderly persons which have still some mobility. An additional challenge is the design and implementation of modular solutions based in open technologies and standard devices will allow a cost reduction.

We are developing software architecture to try of answering to these challenges. According to this goal, we have organized this article as follows. After this introduction, we display some aspects relative to socio-economic perspectives for mobile devices applied to Health Information Services. Section 3 is devoted to functionalities which are linked to a remote management based in wired and unwired solutions. Technological aspects in the framework of customized Services Oriented Architecture are developed in section 4. Finally, some conclusions and some guidelines for future work are sketched in Section 5.

2 SOCIO-ECONOMIC PERSPECTIVES IN HEALTH INFORMATION SERVICES

Survival to infectious diseases (some time ago mortal for involved persons), nowadays generate some kind of permanent disablement involving physical aspects. Traditional hospital services have increasing troubles for supporting the costs linked to the raising of elderly people and different kinds of disabilities or chronic diseases and their corresponding therapies. So, following the Statistiches Bundesamt Deutschland (2006), the cost in 2004 in Germany displays an exponential growth going from 1110 €/inhabitant for age lesser than 15 years till 14.750 €/inhabitant for 85 years and older people. Furthermore, the increasing costs with age, other important aspects concern to the lack of transparency between different agents involved in Health Care Systems. Thus, to improve the health care assistance for citizens, it is necessary to give some steps towards a hierarchised integration of care providers and suppliers in knowledge networks with different kinds of services. The number of service providers is still relatively modest (21 for Europe in 2007), perhaps due to the limited availability of public wireless LAN. With the development of communications and services platforms one can expect a substantial increasing of such number. In the meantime, it is advisable to advance in some aspects regarding services design linked to the application layer.

Hierarchy design must be translated in terms of minimally intrusive sensors and smart mobile devices, able of a periodic communication with a remote server for supervised surveillance and control in and out health care centres. The hardware and software architecture must be applied in different environments, including primary care and self-management and must be controlled in a remote way by experts (doctors, nurses, pharmaceuticals), depending on the disease or the required assistance type. Health experts receive information which is shared by the nearest health care centres, and can provide an assistance to take decisions and to avoid unnecessary interventions. In this way, it is expected to improve the personal assistance, and to reduce the length of hospital stays and the number of beds in hospitals. But, to achieve such expectations, it is necessary to improve the trust in m-devices and the intelligence of system.

Currently, emotional intelligence linked to the personal contact with the expert is the most difficult challenge, and technological solutions can not replace such direct contact. Nevertheless most devices are focused towards diseases and therapies for elderly people, it is expected that in a first stage main users will be younger people with chronic diseases having already some familiarity with mobile devices. In a second stage and similarly to the generalised use of increasingly smart phones by elderly people, it is plausible that the feeling of “Forever Young” will have an effect on potential demand of electronic devices for larger segments of population.

In addition of the economic impact linked to hospital assistance (going from primary care to gate-keeping systems, chronic diseases which can receive attention at home), it is necessary to take in account other pathologies. Some new pathologies are present as an increasing in percentage of risks to chronic diseases. Unfortunately, prevention is still far from being reached in a large amount of such “social” diseases, but in the meantime one can try of mitigating some minor effects in preliminary phases of diseases. In particular, some minor illness effects in elderly people are linked to lack of orientation, anxiety crises or identity loss feeling in preliminary stages of mental diseases (first stages of Alzheimer, e.g.).

3 FUNCTIONALITIES

A classical requirement concerns to simplify the access to clinical data, for which there exist already efficient solutions based in wired Interned solutions, in despite of a scarce application in Health Care Systems. It is necessary to apply them, to avoid an excess administrative overhead and a frustration feeling from patients and medical staff.

Main lines of unwired mobile services must be linked with knowledge generation arising from provision, analysis and diagnosis of physiological aspects. The scarce development of ICT infrastructures in hospital or health care institutions in Spain and the raising of costs, have motivated an orientation with a more limited reaching than it could be expected. Thus, we have limited ourselves to a design and implementation of an architecture based in mobile devices for Health Information System (HIS) which is labelled as a Mobile Information System for Health Care (MISHEC).

A MISHEC provides parameterized information to medical experts (located at a POC) involving some data (physiological, localization) of mobile patients which can be captured with minimally intrusive sensors and periodically tracked. Such parameterized information is locally analyzed and regularly transferred (by means of wireless communications) to a health care system by means of the PDA. Emergency signal can be generated by the apparition of critical values of individual parameters along a sequence. Alternately, the accumulation of unusual values of several parameters which can be meaningful for dangerous situations is very useful to prevent emergencies; in this case, experts in Medicine must identify index numbers for weighted sum of values depending on the personal characteristics of each patient. Thus, there is no a universal solution and personalisation is crucial for improving the efficiency and the trust of patient on the mobile device.

Nevertheless, the existence of a common application layer, some important differences between wired and wireless internet solutions concern to

- devices: fixed (PC, Mac) vs mobile (smart phones, PDAs, etc)
- Operating systems (Operating Systems, Mac) vs. Specific systems of each mobile device.
- Networks: usual protocols (TCP/IP) vs a plethora of protocols for mobile solutions (CDMA, GSM, TDMA, WLAN, etc by alphabetical order)

Security of ubiquitous wireless networks is similar to wired networks, but they offer the possibility of real-time decision taking. The choice of the best option is not easy, and depending on priorities for the applications layer and the performance of networks providers, it will be necessary to choose between advantages linked to mobility (3G technologies) or bandwidth (WLAN).

4 TECHNOLOGICAL ASPECTS

The design and implementation of software architecture must be enough flexible to be adapted to different scenarios and agents, going from hospital to home-based or self-management healthcare, and including chronic or sporadic interventions following adaptive patterns which can be personalized for each patient, depending on personal characteristics and the context. A general solution is still far from being reached, but a SOA (Services Oriented Architecture) provides a general framework for technological aspects. The current mobile solution has been implemented on a Personal Data Assistant (PDA), allowing a wireless access through Internet to a data source which can be physically located in remote Point of Care (POC) information.

Between the targets of the Challenge 5 (Towards sustainable and personalized healthcare) of the EU initiative are the minimally invasive systems: Solutions for remote monitoring and care. Proposals are expected to develop technological innovations both at component and system levels. Solutions will integrate components into wearable, portable or implantable devices coupled with appropriate platforms and services. Emphasis will be placed on (i) the accuracy of measurements and operation of the devices; (ii) remote control of the devices by health professionals, as well as self-monitoring and autonomous regulation of the devices' own operation, to personalize and optimize care by considering changes in health status, activity levels or response to treatment; (iii) continuous, context-aware, multi-parametric monitoring of health parameters, activity, lifestyle, environment and operational parameters of the devices; (iv) analysis and correlation of the multi-parametric data with established biomedical knowledge and expertise to derive clinically relevant and useful information (v) clinical workflows to support remote applications, addressing also alarms and crisis management; and (vi) education and feedback to patients. [**Objective** ICT-2009.5.1: Personal Health Systems of 1.1 Challenge 5: Towards sustainable and personalized healthcare]

4.1 *Product lines and web services*

The assembly of new products from software pieces has been one of the main goals of the Software

Engineering discipline from its beginning, with the aim of obtaining important benefits, expressed in productivity and quality terms, when an industrial reuse approach is introduced in the software process.

The basic reuse unit was initially the module, but the class occupied readily this role due to the object-oriented paradigm popularity. However, these reuse initiatives failed in establishing a systematic reuse approach because these efforts only provided reuse at small-scale level. For this reason the reuse unit has increased its size and complexity towards coarse-grained reusable software artifacts as frameworks or components. Nevertheless, even with these coarse-grained constructions, the expected benefits have not appeared because these large elements present a bottom-up reuse approach (i.e. the composition of arbitrary components to construct systems) that has failed in practice (Bosch 2000)

Finally, product lines appear as the more successful approach in the reuse field, because the combination of coarse-grained components, i.e. software architectures and software components, with a top-down systematic approach, where the software components are integrated in a high-level structure. The product line concept emerged in the eighties in the business schools, aiming at achieving scope economies through synergetic development of products (Knauber & Succi 2001).We have proposed an adaptation of the Unified Process to include the specific techniques of Product Line Engineering in a process parallel to Application Engineering (Laguna et al. 2003).

The UML models are diagrams that are organized in packages. Apart from the base package, each optional feature must have a counterpart in a package which includes the set of class diagrams, use cases and sequence diagrams that are the solution that achieve this feature. The packages are related using the UML package merge mechanism. In Laguna et al. (2003), we have explained the application of this technique to the organization and configuration of the product line architecture.

Web services have open the way for a new type of systems. Services let us design systems in a modular way in a distributed environment, adhering to standard interfaces — using, for example, the Web Services Description Language (WSDL). Users can create systems by reusing and composing Web services, enabling the product line paradigm. Web services are tools that users and developers can reuse in various applications by exposing well defined interfaces and APIs. The spectrum of collaboration ranges from process centric to ad hoc collaboration models. Process-centric collaboration defines process models and follows a top-down approach (Figure 1). The reusability is generally high, because we can apply process models several times. However, flexibility is rather limited; if changes occur (such as exceptions), process architects have to remodel the process. It is more flexible but less reusable, because many aspects depend on the actual players (that is, humans) involved in the process (see Figure 1). However, Web-scale collaborations demand a flexible yet reusable approach because they might involve numerous people and software services.

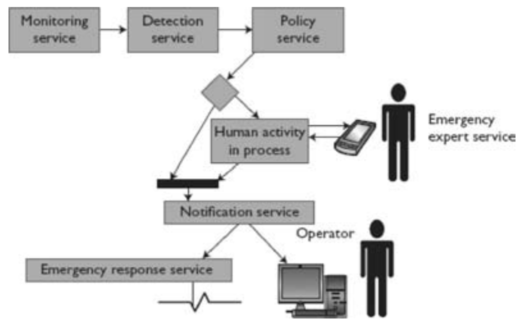

Figure 1. An emergency scenario using monitoring, PDAs and centralized services (Schall et al. 2008).

4.2 *A first example: PDA based health care monitoring*

Our goal is the development of a personal (elderly persons or patients) passive monitoring and assistance with a minimal intervention of Care Health professionals. Across non-intrusive sensors we can gather biological values of our patients with two objectives, the constant capture of information for a later treatment, and the online detection of situations of risk putting in danger the health of the patient. Under this supervised system, intervention would be necessary only when parameters achieve some critical value.

The role of experts in Health Care for a passive monitoring is reduced to a customized system configuration, and the analysis of captured information. Both functions are supervised from remote POC with Internet access, allowing ubiquity performance of solutions, which are considered essential for the application.

The detection of risk situations is a very important feature of this system. Remote detection of risks by Health Care experts is performed by means of the configuration of a set of rules that consider the values captured by the different sensors, individually or in an aggregated way; so, the weighted sum of several innocuous parameters can become a dangerous situation for certain persons, for instance. In this way, it is possible to detect a risk situation in the patient who can put in danger his life; and report at once to the services of assistance, indicating even the location of the patient thanks to a GPS incorporated in the PDA.

Geographical localization gives gather functionality to this solution. So, it is possible not only the

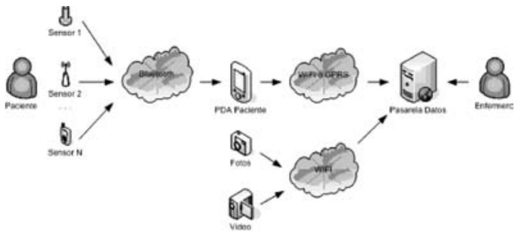

Figure 2. A flowchart for the developed smart device.

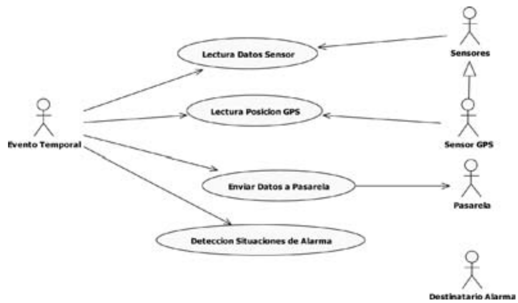

Figure 3. Use cases of the system.

monitoring and location of a patient or an elderly person, but also other people, including workers and sportsmen in open fields which can be assisted in risk or accident situations. In this case, we have restricted ourselves to persons with certain problems of health, or wishing to gain independence being monitored not by a person, but by a device, keeping located anywhere and anytime. However, the Services Oriented Architecture can be reused for other services involving working or leisure activities.

The availability of simple non-intrusive sensors provides a support for monitoring and tracking which can be used and adapted by non qualified personnel, under certain information protocols. In this way, it is possible to gather information about physiological parameters and journey performed by each person. The device routes the information through a wireless network to a PDA device or directly to a residential gateway. A general view of the system is shown in the following diagram.

Nowadays, there exists a great variety of non-intrusive sensors on the market, but not so many with wireless technology that they allow to carry out this system. Wireless technology every day is not only becoming cheaper, but more important, every day is smaller and with fewer needs of electrical consumption, a feature that allows to sensors have a fewer cost of production. Their integration in small compact gateways with appropriate visualization devices opens new working lines and business perspectives with wide applications to other productive sectors including monitoring and management services in AEC environments.

Nowadays, the implementation of the system is in process. The use cases of the system are shown in the figure appearing below:

As a first example of the product family in the Health Care domain we have proposed a system with the following features:

Some requirements of the software application are relative to customization (linked to characteristic of patients and sensors), characterization of risks situations and corresponding rules, and a remote configuration from Health Care System (HCS). In this way, we intend to provide a support for a constant

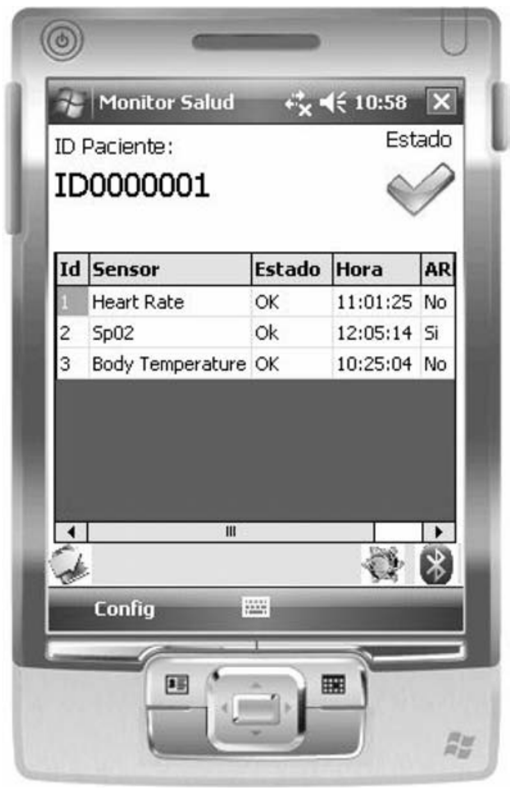

Figure 4. Main form of the application.

monitoring for any location of patients (outdoor of health care institutions).

To prevent failures, it is necessary to verify and validate the right functioning of sensors providing a lecture and transmission in the allowed range to the residential gateway, the local and remote validation of the current state of the residential gateway and the shipment of alert signals to the user and HCS in case of failures. Furthermore the internal validation of right functioning, external applications concern to parameters evaluation (following individual and weighted patterns), identification of risk situations, and alarms generation in presence of critical values for parameters evaluation, and the information shipment with the last available location.

Currently, the main form of the application shows the state of the patient, and the state of the captured data and communication of every sensor. It shows too, if the residential gateway is running normally and when a sensor data is being captured.

The current configuration of the hardware platform is composed of a low-cost PDA with standard localization (GPS based) and communications system (WiFi, Bluetooth, GSM). Computer implementation has been developed under Microsoft (C# language). This architecture fulfills usual constraints relative to a customized configuration, the use of Web services for communications between PDA and residential gateway, and the security in the data transmission.

5 CONCLUSIONS AND FUTURE WORK

In this article, an example of application of the mobile technology to healthcare is presented. Non-intrusive sensors allow obtaining real-time information relative to health parameters. The identification of critical values for parameters of every sensor (and the combination of them) provides the basis for risks minimization in active patients. Our idea is to apply this architecture to an ample variety of sensors, opening the possibility of combining diverse parameters in logical expression that can defined by medical specialists. The architecture is based in mobile devices (sensors and PDAs or SmartPhones) and a central system that keeps the concrete configuration and the up-to-date history of each controlled patient.

The diversity of available mobile device, sensors, parameters, and personalized threshold alarms, drives us to the product line paradigm. Our intention is to analyze in detail all the technical possibilities by means of a feature model to be validated with medical experts. The architecture we are using is intended to support the successive addition of new sensors and the corresponding software packages. This addition supposes a big amount of pending and challenging work.

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A feed forward scheme for building systems control

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ABSTRACT: In a simulation-based feed forward control approach, systems control decisions are made in that presently available (conceivable) control options are virtually projected onto a future time step, and the respective consequences (values of pertinent performance indicators) are predicted, compared, and ranked. This paper presents the results of recent efforts to implement and test simulation-based feed forward approaches for building systems control in lighting, shading, and ventilation domains.

1 INTRODUCTION

This paper presents selected recent results of a long term research effort toward the implementation of a simulation-based feed forward control approach for the operation of indoor environmental control systems in buildings (Mahdavi 2008). Specifically, prototypical implementations of this approach for ventilation and lighting systems are introduced. Thereby, real-time sensing and numeric simulation are applied to dynamically control the position of devices for lighting and ventilation (windows, blinds, luminaires).

The control system in the respective scenarios possesses an internal digital representation consisting of room, context (external conditions), and occupancy models. The room model entails information about geometry, furniture, location and size of windows, reflectance and transmittance properties of surfaces, as well as the position of virtual sensors that monitor pertinent performance parameters such as room air temperature, relative humidity, CO_2 concentration, illuminance levels, light distribution uniformity, and glare indices. The room model provides the basis of system's internal representation and is intended to be dynamically updated using an optically-based location-sensing system (Icoglu and Mahdavi 2007, Mahdavi et al. 2007). The context model (weather and sky conditions) is generated on a real-time basis using a weather station augmented with calibrated digital photography (Mahdavi et al. 2006).

In general, the need for a control action arises if a change occurs in one or more of the following: *a*) Room configuration (e.g. position of furniture and partition walls); *b*) Outdoor conditions (temperature, daylight availability); *c*) Occupancy (presence) and/or occupant settings (e.g., preferred temperature or illuminance levels, weights in the prescribed objective functions).

To provide and maintain the desired performance under such dynamically changing internal and external conditions, the proposed simulation-based feed forward control system operates as follows: *i*) At regular time intervals, the system considers a set of candidate control states (i.e., a set of alternative combinations of the states of control devices such as opening degree of windows, position of blinds, dimming levels of luminaires) for the subsequent time step; *ii*) These alternatives are then virtually enacted via numeric (thermal and visual) simulation. Thereby, the simulation application uses the aforementioned digital representation of the room, context, and occupancy toward the prediction of the implications of these alternative control actions, resulting in values for corresponding performance indicators such as indoor air temperature and task illuminance levels; *iii*) These results are compared and ranked according to the preferences (objective function) specified by the occupants and/or facility manager to identify the candidate control state with the most desirable performance; *iv*) The system either autonomously instructs the pertinent control device-actuator(s) or informs the user to adjust the control state.

In the following, we present preliminary results of recent efforts to further develop and test simulation-based feed forward control strategies in lighting, shading, and ventilation domains. The results so far suggest that the proposed control system has the potential to maximize the values of pertinent thermal and visual comfort criteria while minimizing energy use for space illumination and ventilation.

2 LIGHTING SYSTEM CONTROL

Earlier publications have documented prototypical implementations of a simulation-based feed forward

Figure 1. Internal view of the test room.

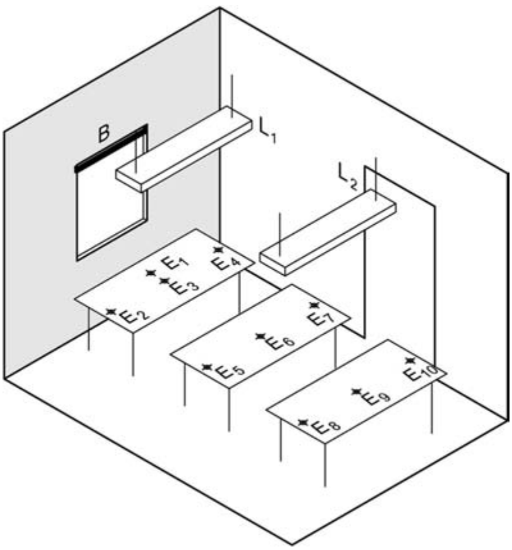


Figure 2. Schematic representation of the test room.

approach to controlling lighting and shading devices in buildings (Mahdavi 2008, Mahdavi et al. 2005). A further recent implementation involved a test room (Figures 1 and 2) in our laboratory (Department of Building Physics and Building Ecology, Vienna University of Technology).

Relevant control devices are, in this case (see Figure 2), two suspended dimmable luminaires (L_1, L_2) and window blind (B). The discretized states of these devices are shown in Table 1 and Figure 3.

Two approaches are implemented to consider daylight availability in the test room. In the first scenario, daylight is emulated using a special flat luminaire (STRATO 2008) placed outside the window of the

Table 1. Discretized device states (dimming steps) for luminaires 1 and 2 (Figure 2).

Dimming state	1	2	3	4	5	6
Power output [%]	0	20	40	60	80	100

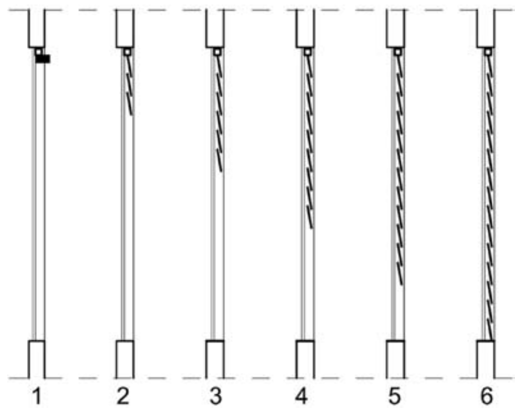


Figure 3. Discretized blind deployment steps.

test room. The luminous flux of this source is controlled dynamically according to available external global horizontal illuminance measured via a weather station installed on top of a close-by university building. This daylight emulator is modeled in the lighting simulation application as a light source with a variable luminous flux output that is dynamically determined as a function the of prevailing outdoor global horizontal illuminance. In the second scenario, sky luminance distribution is dynamically scanned via calibrated digital photography (Mahdavi 2008, Mahdavi et al. 2006). The resulting luminance maps are used as input to the lighting simulation application toward prediction of light distribution inside the test room. Note that, in the latter case, a validation of system's predictions is not possible, as the test room is currently inside a larger laboratory space and does not receive direct daylight.

The control process is as follows. At time t_i, the actual state of the virtual model is used to create candidate options for the state of the building in a future time point t_{i+1}. These options include six different positions of the blind (see Figure 3) and six discrete dimming positions for each of the two luminaires (see Table 1). The options are then simulated using the lighting simulation application RADIANCE (Ward Larson & Shakespeare 2003). Thus, values of multiple building performance indicators (e.g. horizontal illuminance at various locations in the space, illuminance distribution uniformity, different glare

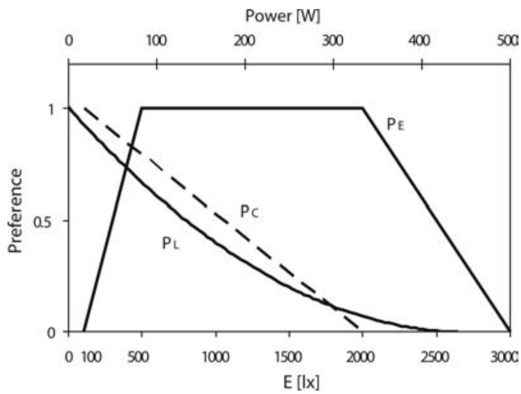


Figure 4. Illustrative preference functions for task illuminance (P_E), electrical power (P_L), and cooling (P_C, here as a function of task illuminance).

indicators, electrical energy use for lighting) are computed for a future time step t_{i+1}. In the present case, the options were compared in view of the corresponding resulting workstation illuminance E (arithmetical average of illuminance levels computed for positions E_1 to E_3 as per Figure 2) and electrical power demand of the artificial lighting. Additionally, a preference value concerning estimated cooling energy requirement was considered. The following demonstrative utility function was applied (Eq. 1).

$$UF = w_E \cdot P_E + w_c \cdot P_c + w_L \cdot P_L \tag{1}$$

In this equation, P_E, P_C, and P_L are the preferences for illuminance, cooling load, and electrical energy consumption. The corresponding weights are represented by w_E, w_C, and w_L. For the purpose of the following illustrative system operation experiments, the values of these weights were assigned to be 0.4, 0.35, and 0.25 respectively. Illustrative preference functions are shown in Figures 4 ($P = 1$ indicates highest, $P = 0$ lowest preference). Note that these preference functions and weights merely serve toward demonstration of the overall system operation. In real use situations, more sophisticated functional relationships between user preferences and ranges of measurable indoor environmental parameters must be formalized and implemented. Moreover, such preference functions need not be static, but can be dynamically manipulated by users to facilitate transient changes in operational requirements.

To illustrate the control functionality and performance, Figures 5 to 8 provide system operation information and validation results for scenario 1 (daylight emulated via flat luminaire). Corresponding information for scenario 2 (sky luminance maps dynamically obtained via calibrated digital sky scanning) is provided in Figures 9 and 10. Figures 5 and 9 show the recommendations of the system (the dimming position of the two luminaires and the deployment position of the blinds) over the course of a reference day (office working hours) for the two scenarios. Figure 6 and 10 show the corresponding values of the external global

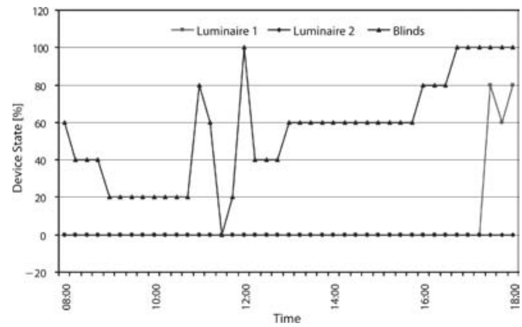


Figure 5. Recommendations (desirable states of lighting and shading devices) of the simulation-assisted lighting and shading control system (Scenario 1) for a reference day.

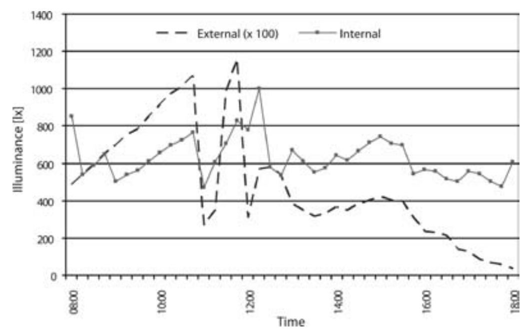


Figure 6. Predicted values of the relevant control parameter (workstation illuminance level) together with the prevailing external global illuminance (Scenario 1).

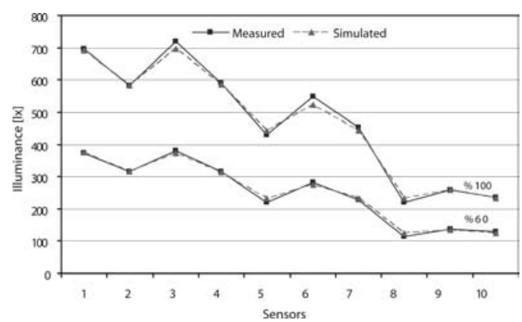


Figure 7. Comparison of measured and simulated illuminance levels at 10 points in the test room (see Figure 2) due to the operation of luminaire 1 for light output levels 60% and 100%.

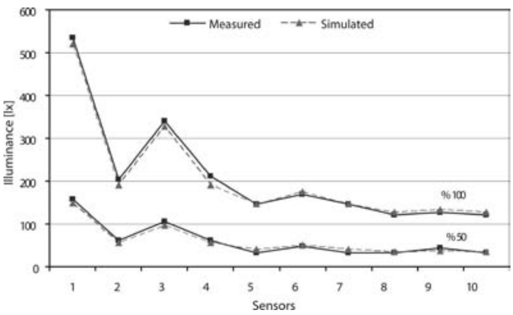


Figure 8. Comparison of measured and simulated illuminance levels at 10 points in the test room (see Figure 2) due to the operation of daylight emulator for output levels 50% and 100%.

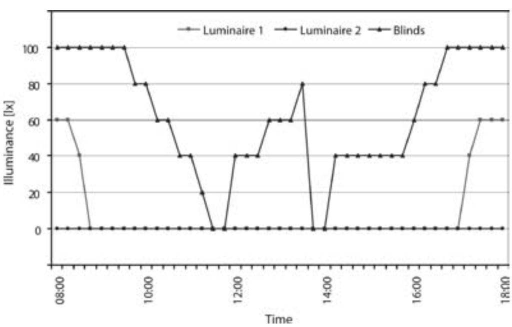


Figure 9. Recommendations (desirable states of lighting and shading devices) of the simulation-assisted lighting and shading control system (Scenario 2) for a reference day.

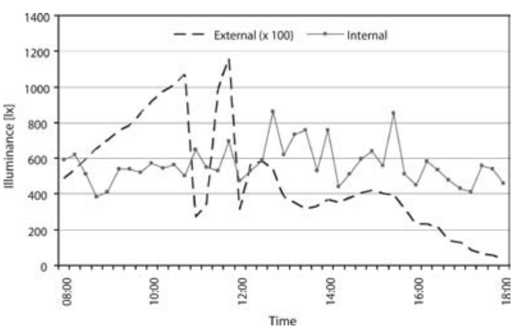


Figure 10. Predicted values of the relevant control parameter (workstation illuminance level) together with the prevailing external global illuminance (Scenario 2).

illuminance and the values of the relevant control parameter (i.e., mean workstation illuminance level, derived as the arithmetical average of the illuminance at points E_2, E_3, and E_4 as shown in Figure 2) for the two scenarios.

These results demonstrate the proper working of the feed forward lighting and shading control mechanism. However, the performance of the system is dependent on the accuracy of the predictions of the system's simulator. As mentioned previously, it was possible to validate the predictions of the control system's embedded lighting simulator. To document this point, Figure 7 shows a comparison of measured and simulated horizontal illuminance levels at 10 locations in the test room (Figure 2) due to the operation of Luminaire 1. Thereby, two dimming states (100% and 60%) are considered. Likewise, Figure 8 shows a comparison of measured and simulated horizontal illuminance levels at the same 10 locations due to the daylight emulator operation (at two output levels, namely 100% and 50%). As Figures 7 and 8 illustrate, there is a high degree of agreement between measured and simulated results.

3 VENTILATION CONTROL

The potential for the application of a simulation-based natural ventilation control strategy has been addressed, in principle, in our previous publications (Mahdavi and Pröglhöf 2005, 2004). In a recent simulation study, we further explored the possibility of feed forward control schemes for window operation in office buildings.

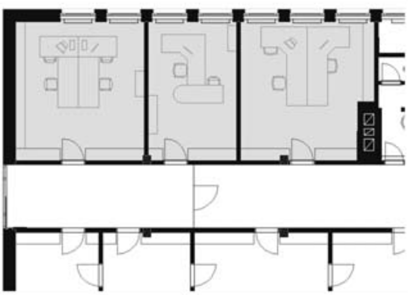
Toward this end, we used the information collected in a previous research project (Mahdavi 2007). Thereby, a number of rooms had been selected in a building in Hartberg, Austria (Table 2). All selected offices face northeast. Windows are equipped with external, manually operated shades as well as curtains. The offices are naturally ventilated via operable ("tilt and turn") windows.

We monitored external weather conditions and indoor climate (in 6 offices on the 1st and 2nd floors of this building) continuously over a period of eight months. Moreover, we also monitored occupancy as well as user control actions (lighting, shading, and window operation).

Given general building information (geometry, construction), local weather station data, as well as detailed information on user presence and control actions, we modeled the thermal performance of this building. Using measured indoor data (room air temperature), the simulation application (EDSL 2008) could be calibrated such that a sufficient degree of agreement between measured and predicted indoor conditions could be achieved. Figure 11 shows, as an example, the simulated and measured indoor temperature in an office for three days in May 2006, together with outdoor temperature (θ_e).

Using the calibrated simulation model, we examined the potential of a feed forward control of window

Table 2. External and internal view of the selected offices and a typical office plan.

External View	
Internal View	
Floor Plan	

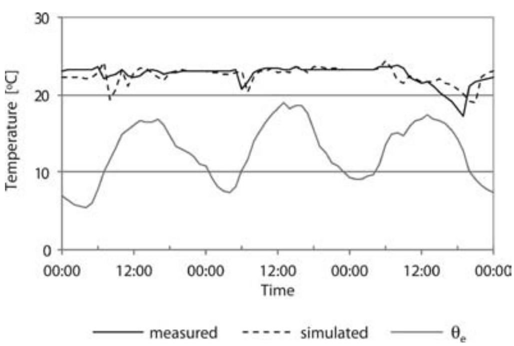


Figure 11. Comparison of the predictions of the calibrated simulation application (indoor temperature in an office over the course of 3 day) with corresponding measurements.

Table 3. Illustrative alternative control scenarios considered for window operation (opening degree in %) during day (from 6:00 to 18:00) and night (from 18:00 to 6:00) in the selected office (window shades in scenarios S1 to S6 are deployed from 6:00 to 18:00).

	Ventilation (window opening degree in %)		
Scenario	6:00 to 18:00	18:00 to 6:00	Shading
S0	3	1	No
S1	3	1	Yes
S2	30	1	Yes
S3	30	30	Yes
S4	10	10	Yes
S5	10	30	Yes
S6	3	30	Yes

positions in an office in the above mentioned building. The main objective was to utilize the day-night difference in outdoor air temperature toward passive space cooling via optimized operation of natural (window) ventilation. Toward this end, a control scheme was conceived as follows: at a specific point in time in a typical (summer) day (d_j), the control unit applies simulation to predict how various window operation regimes would affect the indoor temperature in the offices of the building over the course of the following day (d_{j+1}). An "operation regime" denotes in this context which windows, when, and to which extent, are opened.

In an actual control situation, the weather forecast information for the following day is used as input information for the simulation runs. Thus, amongst a number of discrete alternative window operation scenarios, one could be selected, which, according to simulation results, would minimizes the overheating of the indoor air in the following day. To illustrate this process, Table 3 shows of a number of alternative window operation scenarios (schedule and degree of window opening) in the selected office. Note that, in this example, scenario S0 involves no shading operation, whereas window shading schedule was identical in scenarios 1 to 6: shades were deployed during the day (from 6:00 to 18:00) and were retracted over the night (18:00 to 6:00). Figure 12 includes also outdoor temperature (θ_e).

Comparison and ranking of the simulation results is conducted using Mean Overheating (OH_m) as the relevant performance indicator (Equation 1).

$$OH_m = \sum_{i=1}^{n} \frac{\theta_i - \theta_r}{n} \tag{2}$$

Where θ_i denotes indoor air room temperature (°C) at hour i in day d_{j+1}, θ_r the reference indoor

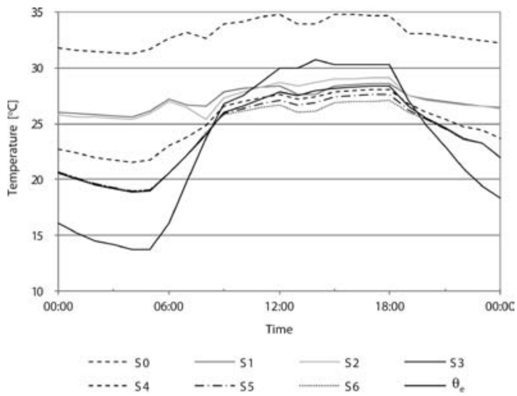


Figure 12. Simulation-based predictions of the indoor air temperature in an office (day d_{j+1}) for alternative control scenarios (1 to 6 as per Table 3) together with outdoor temperature (θ_e).

Table 4. Comparison and ranking of control scenarios (day/night window opening degrees as shown in Table 3) based on predicted Mean Overheating (OH_m).

Scenarios	S0	S1	S2	S3	S4	S5	S6
OH_m [K]	8.2	1.9	2.2	1.3	1.3	0.8	0.4
Rank	7	5	6	4	3	2	1

air temperature for overheating (°C), and *n* the total number of occupied office hours in day d_{j+1}. Note that the term $\theta_i - \theta_r$ is considered only for those hours when $\theta_i > \theta_r$. In our illustrative example, this reference overheating temperature (θ_r) was assumed to be 26 °C.

Figure 12 shows the simulation-based predictions of the indoor air temperature in the selected office over the course of a day (d_{j+1}) for various control options as summarized in Table 3. Table 4 shows the predicted OH_m values for each scenario. The information in this table provides a basis for proactive control decision making concerning the proper operation of windows toward an optimized passive cooling strategy using night-time ventilation.

Note that in this illustrative example, the feed forward control functionality was merely emulated. As a consequence, predictions of the thermal conditions in the office were not based on real-time weather forecast, but conducted using a weather file of the building's location. Thus, weather forecast errors and their implications for the ranking of the options are not considered. Ongoing research explores such implications in view of the stability of system's proposed ranking matrices for alternative control options. As such, in a real system operation scenario, parametric simulations can run on a continuous basis, allowing thus for regular readjustment of weather forecast data and, in case necessary, for revision of recommended control actions.

4 CONCLUDING REMARK

We demonstrated instances of prototypical realization and computational emulation of feed forward systems control strategies in the domain of lighting, shading, and ventilation operation in buildings. While the experiences to date underline the promise of the proposed concept, many challenges must be resolved in the course of ongoing and future research and development. Most of our past efforts have been focused on single system control tasks. Integrated operation of multiple building systems will require full interoperability of control device communication protocols, high-resolution and seamless sensor and actuator networks, substantial computational power, and advanced search and optimization algorithms and methods.

Toward achieving these objectives, we currently pursue both industry-supported experimental (laboratory-based) research and development projects and actual implementation plans in new and existing buildings.

ACKNOWLEDGEMENTS

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User-system interaction models in the context of building automation

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ABSTRACT: This paper describes an effort to monitor, document, and analyze control-oriented occupant behavior in a high-tech high-rise office building in Vienna, Austria. Thereby, over a period of 14 month, 26 open plan office zones were observed in 5 floors, covering altogether 89 building users. We explored potential patterns in collected data, especially in view of the dependencies of the observed user control actions both on indoor environmental conditions and outdoor environment parameter. Such patterns could facilitate the derivation of predictive user control behavior models that could be incorporated in the software applications for building simulation and automation.

1 INTRODUCTION

1.1 *Motivation*

Recently, there has been a growing recognition of the importance of solid, empirically-based information on the patterns of user presence and behavior (especially control-oriented actions) in buildings (Mahdavi 2007). Information on frequency and kinds of users' interactions with buildings' environmental control systems (for heating, cooling, ventilation, lighting, and shading) is valuable for multiple reasons.

Firstly, to generate reliable results, building performance simulation applications require not only sound algorithms, but also accurate input data. Asides from building geometry, construction details, and weather conditions, data on user presence and control actions (i.e. the operation of indoor climate control devices for lighting, shading, heating, cooling, and ventilation) can significantly affect the outcome of simulation-based performance predictions. More reliable information in this area will thus improve the accuracy of performance simulation applications toward more effective building design support.

Secondly, user behavior can affect both buildings' energy performance and indoor climate. Structured knowledge on occupants' control actions can provide feed-back regarding potential energetic and indoor-environmental drawbacks of certain user-systems interaction tendencies and support building management activities and processes toward more efficient building operation regimes.

Thirdly, building automation systems' design, configuration, and operation can benefit from empirically-based user control action models. Especially, in the so-called hi-tech office buildings (involving sophisticated building automation systems) a balance must be achieved between centrally controlled environmental systems operations and user-based interventions in the state of control devices such as HVAC terminals, luminaries, and blinds. User-systems interaction models can be incorporated in the control logic repertoire of such buildings, thus allowing for timely anticipation and proactive accommodation of occupancy needs and requirements, while considering the monetary and environmental implications of alternative operational strategies.

Given this context, the present contribution describes an effort to monitor, document, and analyze control-oriented occupant behavior in a recently constructed and occupied high-tech high-rise office building in Vienna, Austria. For the measurement we concentrated on the standard floors which are open plan offices, hosting up to 94 employees. The open plan office is structured in zones. For the study 9 single-occupancy, 3 double-occupancy and 14 multi-occupancy zones in 5 floors were observed over a period of 14 month.

1.2 *Background*

A large number of studies have been conducted in the past decades to understand how building occupants interact with buildings' environmental control systems such as windows, blinds, and luminaries. A brief overview of a number of such studies is provided below.

Hunt (1979) used time-lapse photography to monitor 3 medium-sized, multi-occupant offices, 2 school classrooms, and 2 open-space teaching spaces resulting in a 'switch on at arrival' probability function

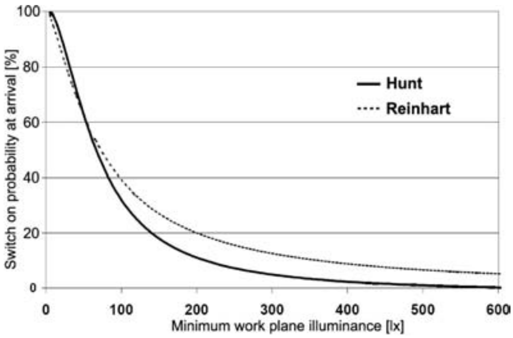

Figure 1. Probability of switching the lights on at arrival in the office.

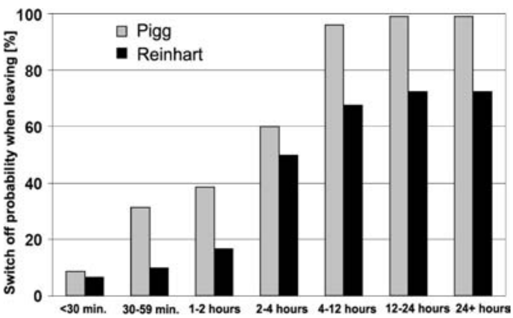

Figure 2. Probability of switching the lights off when leaving the office.

in relation to work plane illuminance level. Hunt's function was reproduced by later studies (Love 1998, Reinhart 2001). It is implied that illuminance levels less than 100 lx lead to a significant increase of the 'switching on' probability (Fig. 1).

Pigg et al. (1996) found a strong relationship between the propensity of switching the lights off and the length of absence from the room, stating that people are more likely to switch off the light when leaving the office for longer periods. Similar relationships (Fig. 2) were found by other studies (Boyce 1980, Reinhart 2001). It was also observed that in the presence of occupancy sensors, people modified their behavior and were 'about half as likely to turn out the lights when they left compared to those without occupancy sensor control' (Pigg et al. 1996).

Boyce (1980) observed intermediate light switching actions in two open-plan offices and found that occupants tend to switch the lights more often in relation to the daylight availability given smaller lighting control zones. Reinhart (2004) suggested that the intermediate 'switching on' events are more common at lower than at higher illuminance values. In this case the intermediate 'switching on' probability function was found to be 2% when the minimum work plane illuminance was between 0 and 200 lx, whereas, at illuminance level above 200 lx, the probability dropped to 0.002%. Based on a related study conducted in a small office building in Lausanne, Lindelöf et al. (2006) suggested an illuminance threshold of 100 lx, above which the probability of intermediate 'switching on' events was very low, whereas under this threshold the probability increased significantly.

Several studies established a seasonal dependency in lighting operation. In a study concerning the manual switching of electrical lighting Boyce (1980) showed that the total number of operating luminaries was less in summer than in winter, corresponding to differences in daylight availability. Likewise, Slater et al. (1998) documented a significantly higher lighting load in January, as compared to April and May.

Rubin et al. (1978) investigated the operation of Venetian blinds in offices in Maryland USA. Deployment of blinds was found to be higher on the south façade (80%) than on the north façade (50%).

A pilot study carried out by Rea (1984) in an office building in Ottawa (Canada) showed that on a clear day a 60% blinds deployment level (east facade) as compared to 40% on a cloudy day.

Based on a study in 4 high-rise office buildings in Tokyo, Japan, Inoue et al. (1988) concluded that the blind operation rates varied greatly in relation to building orientation. Blinds on the east façade were mostly closed in the morning and opened in the afternoon.

Lindsay et al. (1992) conducted a study of 5 office buildings in UK and found a strong correlation between the operation of Venetian blinds and the solar radiation intensity (and sun position). Moreover, blinds were operated more frequently on the south façade.

Rubin et al. (1978) suggested that occupants manipulate shades mainly to avoid direct sunlight and overheating. Rea (1984) concurred that blinds are mostly operated when direct sun light reached the working area. Based on a study in two south-facing single occupancy offices Bülow-Hübe (2000) observed that the shades were closed to protect against sun-triggered glare.

According to Inoue et al. (1988), above a certain threshold of vertical solar irradiance on a façade (50 $W.m^{-2}$) the deployment level of shades is proportional to the depth of solar penetration into a room. This conjecture was corroborated by Reinhart (2001) (Fig. 3).

Once closed, shades seem to remain deployed until the end of the working day or when visual conditions become intolerable. Rea (1984) observed a rather low rate of blinds operation throughout the day, implying that occupants' perception of solar irradiance is a long-term one. Inoue et al. (1988) observed a specific pattern concerning the relation between blind operation and incident illumination on the façade

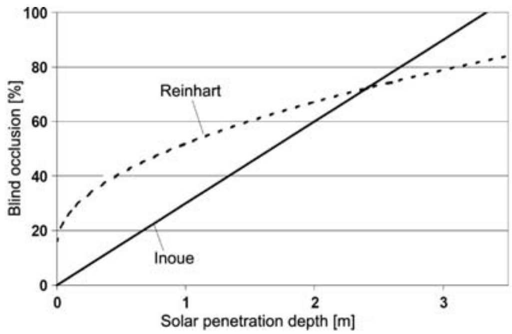

Figure 3. Mean blind occlusion in relation to the solar penetration depth on SSW façade (vertical solar irradiance above 50 W.m^{-2}).

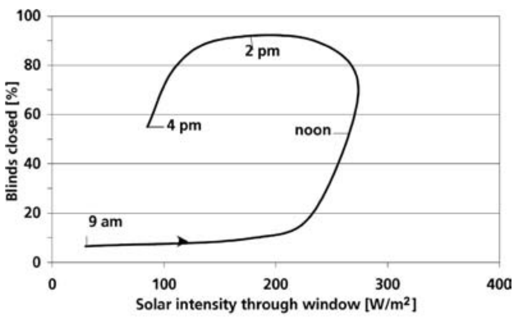

Figure 4. Percentage of blinds closed for SSW façade in relation to the vertical solar irradiance.

(Fig. 4). Inoue concluded that occupants largely ignore short-term irradiance dynamics.

Future investigations of the manual operation of shades systems must address more building and shading system types. An important requirement for future studies is that they should carefully monitor occupancy in the selected spaces in order to eliminate the uncertainty regarding the reason for the rather small number of opening/closing actions.

Fritsch et al. (1990) monitored the use of windows in four offices in summer and winter conditions at LESO. The results suggested that window positions persist over long time intervals. Nodependencies on contextual parameters could be established. A conjecture was made that the only factor influencing the position of a window in a specific time step is the position of the window one time step before. Thus, Markov chains were proposed as a tool to predict window positions.

Herkel et al. (2005) observed window operation in 21 south-facing single offices in Freiburg, Germany (with smaller and larger window units). Parameters such as window status, occupancy, indoor and outdoor temperatures, as well as solar radiation were regularly recorded. The analysis of the results revealed a strong seasonal pattern behind the window operation. In summer, 60 to 80% of the smaller windows were open in summer, in contrast to 10% in winter. The frequency of window opening/closing actions was observed to be higher in swing seasons spring and autumn. A strong correlation was found between the percentage of open windows and the outdoor temperature. Above 20 °C, 80% of the small windows were completely opened, whereas 60% of the large windows were tilted. Concerning the relationship to the time of the day, the windows were more frequently opened/closed in the morning (9:00) and in the afternoon (15:00). Moreover, window operation occurred mostly when occupants arrived in or left their workplaces. At the end of the working day, most open windows were closed.

Bourgeois (2005) monitored the manual operation of windows in 211 mechanically ventilated offices in a university building in Quebec, Canada. Simultaneously, the status of windows, lights, and blinds were recorded, together with outside climatic conditions (air temperature, solar radiation). The results suggested a clustering of the population as ‘active’ and ‘passive’ occupants.

The knowledge of occupants’ presence in buildings is of course crucial for the derivation of user-system interaction models. Newsham et al. (1995) presented a stochastic model called LIGHTSWITCH to predict occupancy as well as manual lighting control actions based on measured field data in an office building in Ottawa. In a further development, Reinhart (2004) developed LIGHTSWITCH 2002 using a dynamic stochastic algorithm. Based on an occupancy model and a dynamic daylight simulation application, predicted manual lighting and blind control actions provided the basis for the calculation of annual energy demand for electrical lighting.

Page et al. (2007) hypothesized that the probability of occupancy at a given time step depends only on the state of occupancy at the previous time step. As suggested by Fritsch (1990) in relation to window operation, Page explored the use of Markov chains toward occupancy prediction. The measured data from five single offices of the LESO-PB building was used to calibrate and validate the model. A probability profile for occupants’ presence was used as well as a mobility parameter, which roughly describes how often people leave their workplace per day. The validation effort revealed the need for the addition of an algorithm to consider longer absence periods (more than one workday). This model is claimed to reproduce periods of absence and presence better than simple exponential distributions. Also, arrival and departure times at the workplace are better predicted. Moreover, the model is claimed to simulate any pattern of occupancy in any type of building, given the availability of required input information.

Most studies of user-system interactions are conducted for individual building systems (lighting, shading, etc.). Bourgeois (2005) attempted to bridge the gap between energy simulation and empirically-based information on occupant behavior via a self-contained simulation module called SHOCC (Sub-Hourly Occupancy Control) that was integrated in ESP-r application (ESRU 2002).

Future research in the area of occupants' control-oriented behavior in buildings must consider more building types in different climatic and cultural settings, as well as long-term monitoring and collection of high-resolution data. Moreover, efforts are needed to improve and – if possible – standardize the pertinent research designs and methods (length and frequency of monitoring, building control systems, representative sampling, equipment configuration, data resolution, analysis methods). This would allow for systematic comparison and aggregation of results toward formulation of valid and broadly applicable models of occupants' presence and actions in buildings.

2 APPROACH

As mentioned in the introduction section, the present work describes an effort to monitor, document, and analyze control-oriented occupant behavior in a recently constructed and occupied high-tech high-rise office building in Vienna, Austria. The building (in this paper abbreviated as UT) houses the headquarter of one of Austria's largest insurance companies. It was constructed from May 2000 till June 2004.

The building has a double façade with floor-to-ceiling window elements that users can manually operate. The envelope includes, in addition to the centrally controlled Venetian blinds within the double façade, interior roller blinds that can be controlled by the users. The Venetian blinds are micro perforated at the eye level to enable visual contact to the outside. Moreover, the upper third portion of the blinds does not block but redirects sunlight toward the office ceiling. Occupants can select the intensity level of the recessed luminaries in terms of three discrete steps.

The floor plan is oval in shape and the workplaces are situated next to the perimeter (Fig. 5). The basic structure of the standard floor is given by 1.3 m wide façade fields that encompass installations for ventilation, heating, cooling and lighting and can be controlled individually. To simplify their control, the fields are grouped into zones. The occupants of a zone control the same luminaries and shading devices. The raised floor contains supply air inlets as well as convectors for heating. Radiant cooling units as well as return air outlets are integrated in the suspended ceiling. Zones can be reconfigured by software only; no hardware change is necessary. In most cases there is no physical boundary between the zones in the open plan office.

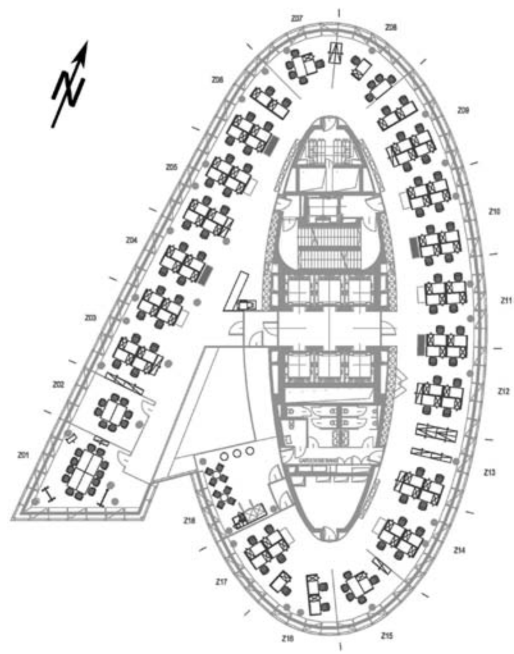

Figure 5. UT standard floor plan with zones and orientation.

The memory functionality of this building's automation systems together with additional sensory installations of our research group provided continuously monitored data concerning various control events and states (occupancy, indoor and outdoor temperature and relative humidity, external air velocity and horizontal global irradiance, status of electrical light fixtures, position of shades) every five minutes. Given the very large amount of collected data, a dedicated SQL-based database was developed to store data and facilitate flexible queries. We compiled and analyzed collected data, especially in view of occupancy patterns and possible dependencies of user control actions both on indoor environmental conditions and outdoor environment parameter. Moreover, we explored the potential for derivation of predictive user control behavior models from the collected data and the integration of such models in the software applications for building automation.

3 RESULTS

3.1 *Occupancy*

Figure 6 shows derived occupancy levels (in % of full occupancy) in single, double, and multiple occupancy offices, as well as in all zones for a reference day that

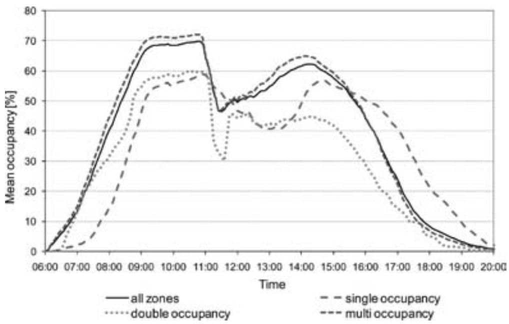

Figure 6. Derived mean occupancy level over the course of a reference day for single, double, and multi occupancy zones, as well as for all observed workstations.

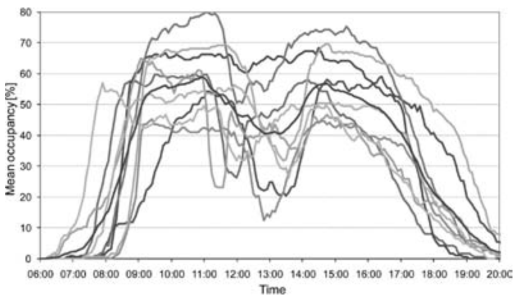

Figure 7. Derived occupancy level for different single occupancy zones over the course of a reference day.

represents the entire observation period. The respective curves are based on observations of presence patterns of 89 employees. To illustrate the considerable differences between the presence patterns of individual occupants, Figure 7 shows occupancy levels for single occupancy zones over the course of a reference day.

3.2 *Lighting*

Figure 8 shows the observed mean lighting load (in $W{\cdot}m^{-2}$) in 26 zones for a reference day (from 6:00 to 18:00), together with mean occupancy level and external global horizontal irradiance.

In UT users can operate ambient lighting from their desktop computers. Thereby, they can increase the light level (from 0 lx to 300 lx, from 300 lx to 500 lx, or from 0 lx to 500 lx) and decrease it (from 500 lx to 300 lx, from 300 lx to 0 lx, or from 500 lx to 0 lx). Therefore there are 3 types of 'switch on' and 3 types of 'switch off' actions. Our observations suggest that, in the overwhelming majority of the cases, light levels were either increased (switched on) from 0 lx to 500 lx, or decreased (switched off) from 500 lx to 0 lx (Fig. 9). The reason for the much larger number of switch on

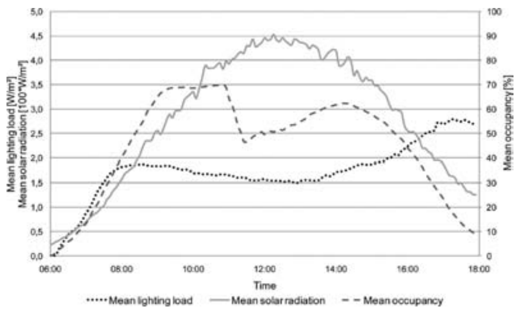

Figure 8. Mean lighting load (in $W{\cdot}m^{-2}$) for a reference day together with mean occupancy level and external global horizontal irradiance ($100 \times W{\cdot}m^{-2}$).

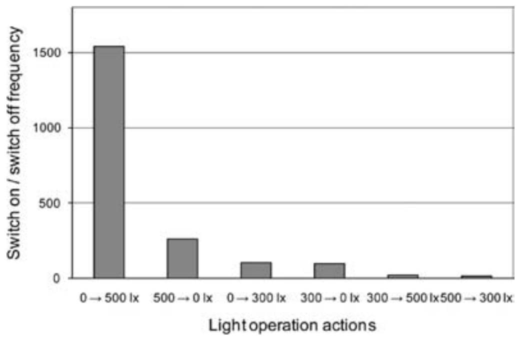

Figure 9. Frequency (absolute number) of observed 'switch on' and 'switch off' actions between 06:00 and 18:00.

actions (as compared to switch off actions) is the operation of the building's automation system, which takes over the control of luminaries at 18:00 every day.

Figure 10 illustrates the relationship between the normalized relative frequency of light switch on actions and indoor light levels (horizontal illuminance levels as measured by the building automation system's ceiling-mounted light sensors). Note that for this analysis (and in contrast to Figure 9), only those time intervals are considered where the shades were fully open. Figure 11 shows the relationship between the normalized relative frequency of 'switch on' actions (0 lx to 500 lx) in the observed zones and the vertical global irradiance incident on the façade measured for the orientation of the respective zones. For this analysis, only those time intervals are considered when all shades (internal and external) were open.

Figure 12 shows the duration of electrical lighting operation (expressed as percentage of respective overall occupied hours) in all monitored zones for December and June (between 06:00 and 18:00, all shade positions).

Figure 13 shows the relationship between the mean effective electrical lighting power (expressed as the

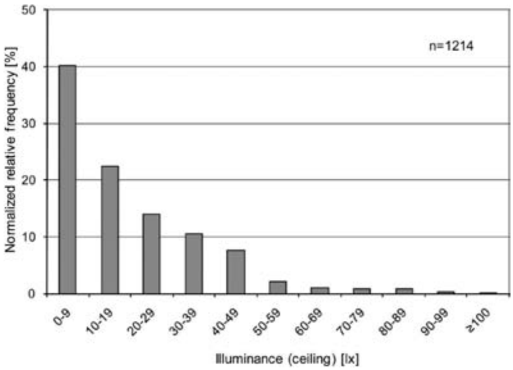

Figure 10. Normalized relative frequency of ‘switch on’ actions (0–500 lx) as a function of internal horizontal illuminance at the office ceiling, between 06:00 and 17:55 (all shades open).

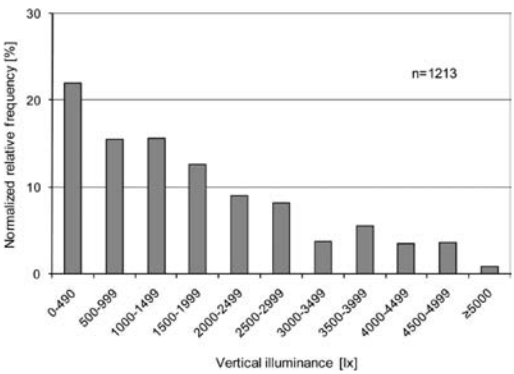

Figure 11. Normalized relative frequency of ‘switch on’ actions (0–500 lx) as a function of vertical illuminance, between 06:00 and 17:55 (all shades open).

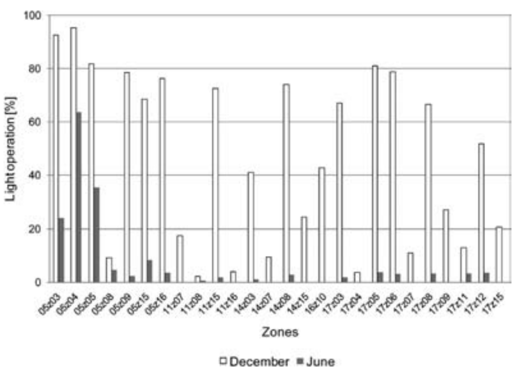

Figure 12. Duration of all light operations in percentage of respective overall occupied hours in all monitored zones for December and June (time intervals between 06:00 and 18:00, all shade positions).

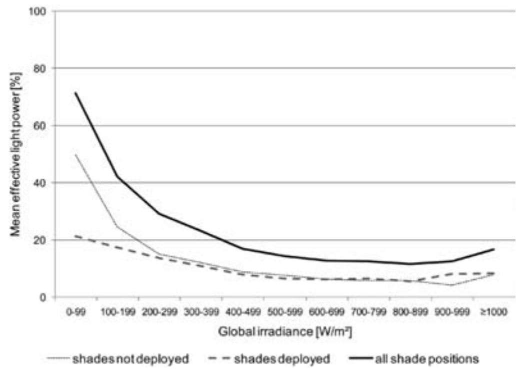

Figure 13. Mean effective electrical lighting power (as the percentage of installed lighting power) averaged for all zones (for time intervals between 6:00 and 18:00) plotted against external global horizontal irradiance (time intervals with and without shade deployment are shown separately).

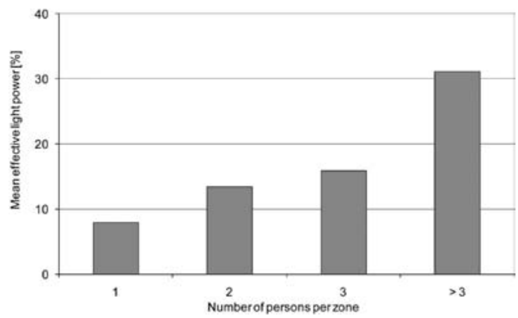

Figure 14. Mean effective light power for each zone differentiated according to the number of occupants per zone (occupied hours between 6:00 and 18:00, all shade positions).

percentage of installed lighting power) averaged for all zones (for time intervals between 06:00 and 18:00) and the external global horizontal irradiance. Time intervals with and without shade deployment are shown separately, together with the function for all time intervals.

Figure 14 shows the mean effective light power (expressed as the percentage of installed lighting power) for each zone (for time intervals between 6:00 and 18:00), whereby the zones are differentiated in terms of the number of occupants that are assigned to them.

4 DISCUSSION

The UT case study supports a number of initial conclusions:

- The overall occupancy pattern (Figure 6) roughly resembles those obtained from other office buildings (see, for example, Mahdavi 2007). Mean occupancy is rarely above 70%. This fact, together with the significant differences in individual occupancy patterns (Figure 7) implies the importance of high-resolution zoning strategies for environmental controls of office buildings. An interesting aspect in the data shown in Figure 6 concerns the differences in the occupancy patterns of single, double, and multi occupancy zones. Occupants of single and double offices appear to spend less time in the building. Specifically, occupants of single offices seem to arrive later, observe a later lunch break, and also leave their offices later. A possible explanation may be the higher positions of the single office residents, providing them with more flexibility in the design of their schedules.

– The light operation over the course of a reference day appears to follow a three-phase pattern (see Figure 8). The initial – early morning – phase follows the occupancy pattern (up to about 8:00). However, with increasing outdoor illuminance level, the further increasing occupancy does not translate into higher light operation (in fact a slight decrease is observable in the data). The third phase (after about 14:00) involves an increase in light operation in tandem with decreasing outdoor illuminance, even though the occupancy rapidly decreases. This implies that many occupants leave their offices without turning the lights off. This conclusion is corroborated by the results shown in Figure 9: the absolute number of light switch on actions is significantly higher than light switch off actions. As Figure 14 suggests, light operation correlates with the number of occupants in a zone. This may be in part due to the higher proximity of the users in single and double occupancy offices to the façade. Moreover, the probability of lighting switch on actions (and the resulting higher light usage) could plausibly increase with the number of the occupants in a zone.
– As Figure 10 indicates, the frequency of light switch on actions clearly correlates with light levels in the zone as monitored, in this case, with building's ceiling-mounted illuminance sensors. There is an overall agreement in the tendency of this result with those documented in a number of previous studies. However, given the complex relationship between measured illuminance at ceiling and at workstation, it is not possible to directly compare these results with similar analyses in the past research (see, for example, Figure 1).
– The results depicted in Figures 11, 12, and 13 suggest that the lighting operation behavior is related to outdoor illuminance conditions as well. However, we could not establish a relationship between zone orientation (north, south, etc.) or zone elevation (lower versus higher floors of the building) and the lighting operation frequency. Moreover, the light operation dependency on external conditions did not seem to be affected by the operation of shades (see Figure 13). In fact, the only instance where a difference between intervals with and without shading was observed concerned external irradiance levels below $200\,W \cdot m^{-2}$. Remarkably, in this case the lights were less operated when the shades were deployed. A possible explanation could be the contribution of additional light reflection due to deployed (light gray) shades.

5 CONCLUSION

The results of the UT case study provide a case in point for the feasibility of the research objectives outlined in the introduction of this paper:

Firstly, additional data was collected to augment existing databases on user presence and control actions toward improving the accuracy of performance simulation applications for more effective building design support.

Secondly, collected user behavior data (for instance low frequency of user-based light switch off actions) can provide feed-back regarding potential energetic drawbacks of this user-systems interaction tendency and support building management toward more efficient lighting operation strategies.

Thirdly, empirically grounded user-systems interaction models (for example, the dependency of user-based lighting operation on external illuminance levels) can be incorporated in the control logic repertoire of the building, thus enabling the automation system to proactively accommodate occupancy needs, while meeting efficiency requirements.

ACKNOWLEDGEMENTS

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Multiple model structural control and simulation of seismic response of structures

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ABSTRACT: The paper is devoted on the problem of multiple model structural control. An approach for multiple model active/semi-active structural control realized with a number of active bracing control systems, where each system corresponds to different device or combination of devices for structural control is proposed. After determination of frequencies characteristics, resonances and anti-resonances a decision about including or not some parts of the system into the total control system is taken. This leads to reconfiguration of the structural control system. Different models of seismic non-stationary excitations are implemented for evaluation and assessment of different combinations of devices included into selected multi-model structural control system.

1 INTRODUCTION

A very promising method in earthquake engineering for protection of high – risk and very important structures against destructive influence of strong motion seismic waves is structural control. Structural control provides possibility to realize measures for reduction of seismic vulnerability of high risk structures, like nuclear power plants, bridges, lifelines, dams, high-rise buildings (Radeva et al. 2005).

Displacements and velocities of the structure during earthquake are not absolute but depend upon inertial reference frame in which they are taken. The need of strong motion and structural response measurements by accelerographs and their modelling by computer simulation enable earthquake engineers to compare and study the behaviour of structures during earthquakes regarding their overall characteristics and potential of structural damages (Radeva et al. 2006).

The purpose the structural response modelling is to analyse it behaviour during the vibrations caused by earthquakes (Nishitani et al. 2003). Their direct measurement on arbitrary locations on large-scale structures is difficult to achieve. During seismic activities this difficulty is exacerbated, because the foundation to which the structure is attached, is moving with the ground and does not provide an inertial reference frame (Scruggs & Iwan 2003). Thus, control algorithms that depend on direct measurements of the displacements and velocities may be impractical for full scale implementations (He et al. 2003).

In this research are concerned acceleration feedback strategies for multiple model structural control with semi-active hydraulic dampers and active bracing control systems for reduction of structural response during seismic activity.

2 MULTIPLE MODEL STRUCTURAL CONTROL

2.1 *Control setup*

The multiple-model active and semi-active structural control is very attractive especially for large-scale systems. In this paper under consideration is multiple-model active bracing control system, where each system corresponds to different device or combination of devices for structural control. In the semiactive framework, after determination of frequencies characteristics of the earthquake, resonances and anti-resonances, is taking decision about including different subsystems into the overall control system. This is realized with gain scheduling control strategy. In the active framework the movements of the structure is measured and on the base of measured results is determine the best

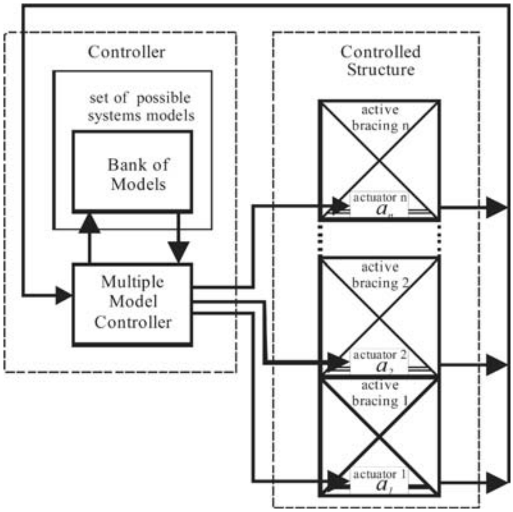

Figure 1. Seismic structure and multiple model control system.

possible control configuration. This leads to reconfiguration of the structural control system – sliding mode control strategy.

The control system consists from two main parts – controller and controlled structure (Fig. 1). It is assumed that many actuators a_1, a_2, ..., a_n, can be switched on in the structure for accomplishment of the control aim. A *set of possible system models* are designed (Murray-Smith & Johansen 1997). Each of these models corresponds to a different system's configurations - with one actuator or with different combinations of actuators. The decision about reconfiguration of the system is taken on the base of analysis of frequency responses, and especially resonance and anti-resonance frequencies (Ichtev & Radeva 2008).

On the base of resonance and anti-resonance frequencies from the set of all possible models was made a subset selection. This set will be referred as *Bank of Models*. Each model from the model bank corresponds to a particular working regime of the system or to a different system scheme – system in different control configuration. The model bank design phase is done offline. This means that there is no need for model design during the active phase of the earthquake. By doing so the number of on-line computations is minimized. On the other hand, the model bank should be designed in such way that can represent all necessary systems combination to counteract any earthquake. This means that for each possible main earthquake frequency (resonance) the system should provide a control combination that sufficiently decreases the effect of the earthquake. If total elimination of the negative effect of the earthquake is impossible then at least the chosen control configuration should be able to ensure the structural integrity.

During the active faze of the earthquake on-line estimation of the seismic signal resonance is realized. This information is used for *Multiple Model Controller* reconfigurations. The reconfiguration task is performed by choosing such control configuration from the model bank that ensures best suppression of the momentary earthquake resonance. In accordance with selected model, the controller switch on, or switch off the corresponding actuators. By doing so the controller is realizing *sliding mode control* for the system with a variable in time structure. In this way, an adaptation of the control system to the seismic signal is accomplished.

2.2 *Structure models and controllers*

The following matrix differential equation is assumed for a mathematical model of the structure, presented as (1)

$$\mathbf{M}\frac{d^2\mathbf{Y}}{dt^2}+\mathbf{C}\frac{d\mathbf{Y}}{dt}+\mathbf{KY}=\mathbf{FV}+\mathbf{BU}. \quad (1)$$

Here $\mathbf{Y}$ is n dimensional vector of the movements in the main points of the structure, $\mathbf{V}$ is vector representation of the external seismic forces, $\mathbf{U}$ is n dimensional vector of the control signals (it is assumed that control action can be applied to all n basic points of the structure), $\mathbf{M}$, $\mathbf{C}$, $\mathbf{K}$, $\mathbf{F}$ and $\mathbf{B}$ are matrixes, which represent mass, damping, stiffness, input and control correspondingly.

The feedback principle can be applied for control purpose of this structure. Control vector $\mathbf{U}$ is computed using information from the vectors of the movements $\mathbf{Y}$, velocities $d\mathbf{Y}/dt$, accelerations $d^2\mathbf{Y}/dt^2$, as well as combination of these vectors at the structure's basic points. The most general description of the controller can be written in the form (2)

$$\mathbf{U}=-\mathbf{R}_a\frac{d^2\mathbf{Y}}{dt^2}-\mathbf{R}_v\frac{d\mathbf{Y}}{dt}-\mathbf{R}_y\mathbf{Y}. \quad (2)$$

Here $\mathbf{R}_a$ is the feedback matrix in respect to accelerations, $\mathbf{R}_v$ is the feedback matrix in respect to velocities, and $\mathbf{R}_y$ if the feedback matrix in respect to position's movements.

The equation for the closed loop system can be obtained, by substituting the expression (2) into equation (1) as (3)

$$(\mathbf{M}+\mathbf{BR}_a)\frac{d^2\mathbf{Y}}{dt^2}+(\mathbf{C}+\mathbf{BR}_v)\frac{d\mathbf{Y}}{dt}+(\mathbf{K}+\mathbf{BR}_y)\mathbf{Y}=\mathbf{FV}. \quad (3)$$

By comparison between equations (3) and (1), can be observed that components $\mathbf{R}_a$, $\mathbf{R}_v$ and $\mathbf{R}_y$ of the control signal are modifying the plants matrixes **M**, **C** and **K** independently. The role of the matrixes **M**, **C** and **K** over the dynamics of the structures is well studied. This makes equation (3) suitable for analysis of the controls signal impact on the systems dynamics (in particular the effect on the discussed below resonance and antiresonance frequencies). This will significantly contribute to the controller design.

The impact of the controllers matrixes' over the properties of the closed loop system is analyzed from equation (3), like the matrix $\mathbf{R}_v$ of the velocity feedback modifies and the damping matrix of the structure **C**. This means that through it, it is possible to be increased the overall damping of the system, i.e. to decrease the resonances.

The matrix $\mathbf{R}_y$ of the position feedback modifies the structure's stiffness matrix **K**. This means that with it the resonance frequencies of the system can be changed. Acceleration feedback $\mathbf{R}_a$ has similar impact on the system. It can be stated that the negative acceleration feedback stiffens the system, i.e. it increases its natural frequency.

The negative acceleration feedback has the opposite effect – it lowers the plants frequency, i.e. it is equivalent to the increased elements of **M**. The seismic signals are high frequency signals and this will going to produce positive results for the control.

2.3 *State space model*

The control theory very often uses descriptions in state space form, which is implemented in this paper. The control signal will be applied as state feedback.

The state space description can be obtained in several different ways. Here it is done on base of differential equations. The starting point will be equation (1). This form is commonly used for description of the structures. The differential equation is second order. In state space the equations are first order ones. For solving this problem is introduced a state vector:

$$\mathbf{X}^T = \begin{bmatrix} \mathbf{Y}^T & \dfrac{d\mathbf{Y}^T}{dt} \end{bmatrix}. \tag{4}$$

As a result the differential equation (1) is written according to the standard phase-coordinate canonical form:

$$\dot{\mathbf{X}} = \begin{bmatrix} \mathbf{0} & \mathbf{I} \\ -\mathbf{M}^{-1}\mathbf{K} & -\mathbf{M}^{-1}\mathbf{C} \end{bmatrix}\mathbf{X} + \begin{bmatrix} \mathbf{0} \\ \mathbf{M}^{-1}\mathbf{F} \end{bmatrix}\mathbf{V} + \begin{bmatrix} \mathbf{0} \\ \mathbf{M}^{-1}\mathbf{B} \end{bmatrix}\mathbf{U}, \tag{5}$$

where $I =$ identity matrix.

The output of the system consists only from the first state and can be presented as:

$$\mathbf{Y} = \begin{bmatrix} \mathbf{I} & \mathbf{0} \end{bmatrix}\mathbf{X} + [\mathbf{0}]\mathbf{V} + [\mathbf{0}]\mathbf{U}. \tag{6}$$

The system can be written into the standard Kochi form:

$$\begin{aligned} \dot{\mathbf{X}} &= \mathbf{AX} + \mathbf{BU} + \mathbf{WV} \\ \mathbf{Y} &= \mathbf{CX} + \mathbf{DU} + \mathbf{NV} \end{aligned} \tag{7}$$

By comparison between (7) with (5) and (6) it can be seen that

$$\mathbf{A} = \begin{bmatrix} \mathbf{0} & \mathbf{I} \\ -\mathbf{M}^{-1}\mathbf{K} & -\mathbf{M}^{-1}\mathbf{C} \end{bmatrix}; \ \mathbf{B} = \begin{bmatrix} 0 \\ \mathbf{M}^{-1}\mathbf{B} \end{bmatrix}; \ \mathbf{C} = \begin{bmatrix} \mathbf{I} & \mathbf{0} \end{bmatrix};$$

$$\mathbf{D} = \mathbf{0}; \ \mathbf{W} = \begin{bmatrix} \mathbf{0} \\ \mathbf{M}^{-1}\mathbf{F} \end{bmatrix} \text{ and } \mathbf{N} = \mathbf{0}$$

In the paper it is assumed that the control action can be applied to the all n main points of the construction. The control signal is computed as a state feedback according to:

$$\mathbf{U} = -\mathbf{KX} \tag{8}$$

In the general case, for the purpose of computing the control vector it is necessary to have complete information about the state vector. For large-scale structures some of the sensors will be placed in a long distance from controller. The problem is that it is not expected great reliability of the connections during strong earthquake. In such situation the threat of losing information for some of the states is real. In such cases the control is unreliable. Partial solution to this problem can be obtained by applying distributed control scheme.

3 SEMI-ACTIVE CONTROL

The system analysis and controller design is done in accordance to the frequency response approach, because of the clear physical relation between the frequency response and characteristics of the structures movement. Significant danger during possible earthquake for structural failure is the coincidence of any natural frequency of the structure with the resonance frequency of the seismic signal. This hazard increases when the structures has small damping, i.e. with large resonance picks in the magnitude-frequency response.

In (Ichtev & Radeva 2008) is proposed to control the structure's natural frequencies. For controller design purposes it is proposed to be used following quality criteria: *maximum distance between basic natural frequencies of the structure and resonance basic frequencies of the seismic signal*. In order to apply this criteria, it is essential to have information about the seismic signals. For the spectral composition of the seismic signals or at least his resonance frequencies, some effect can be obtain by the controller if it is tuned in such a way that antiresonance of the structure neutralize some of the main resonances of the bedrock. For more information about semiactive control see (Ichtev & Radeva 2008).

4 ACTIVE CONTROL

4.1 *Multiple-model framework*

The Multiple model approach is first introduced in the fault detection and identification field (Gertler 1998, Patton et al. 2000, Patton 1997) in order to detect and isolate faults in automatic controlled systems. In this paper is applied similar approach for estimation of the current seismic condition. On the base of the working regime estimation the total control is reconfigured in order to insure best possible structural protection.

Multiple model method utilize mathematical model of the monitored plant. Seismic protection systems are characterized by continuous-time operation. Their natural mathematical description is in the form of differential equations, or equivalent transformed representations. The controlling computers operate in discrete time domain. Usually the structural model is described with the same domain like the controller. This is the reason to use discrete time description for the controlled structure. The other reason is that the most physical systems are nonlinear and their mathematical descriptions usually rely on linear approximations.

Sensory measurements are compared to analytically computed values of the respective variable. Such computations use present and/or previous measurements of other variables. The mathematical model describes from one side the relationships between the system inputs and states and from the other the measured parameters. The idea can be extended to the comparison of two analytically generated quantities, obtained from different sets of variables. In either case, the resulting differences, called residuals, are indicative whether the system's behaviour coincides with the tested model. Another class of model-based methods relies directly on parameter estimation.

The generation of residuals needs to be followed by residual evaluation, in order to arrive at detection. Because of the presence of noise, disturbances and model errors, the residuals are never zero, even if the systems operating conditions are precise the same as modelled ones. One way of solving this problem is by testing the residuals against predefined thresholds, obtained empirically or by theoretical considerations.

Usually, for residual evaluation are used methods in state space, which can remove the negative effect from noise and limited number of disturbances. The classifications of these methods are given in (Gertler 1998), (Patton et al. 2000). The most significant of them are:

– *Kalman filter*. The innovation (prediction error) of the Kalman filter can be used as a residual; its mean is zero if the model is correct one (and no disturbances are present) and becomes nonzero if the model changes. Since the innovation sequence is white noise, statistical tests are relatively easy to construct. One way to solve this problem of choosing the right model is by the usage of a bank of "matched filters", one of each possible earthquake frequency and for each possible arrival time, and check which filter output can be matched with the actual observations.
– *Diagnostic observers*. This method gives the freedom in design of the observer. The innovations of the observer also qualify as residuals. "Unknown input" design techniques may be used to decouple the residuals from (a limited number of) disturbances. The residual sequence is coloured which makes statistical testing somewhat complicated.
– *Parity (consistency) relations*. Parity relations are rearranged direct input-output model equations, subject to a linear dynamic transformation. The residual sequence is coloured, just like in the case of observers. The design freedom provided by the transformation can be used for disturbance decoupling.

It has been proven that, there is a fundamental equivalence between parity relations and observer based design, in that the two techniques produce identical results if the generators have been designed for the same specification (Patton 1997).

4.2 *Hybrid systems*

One way of representing systems with strong nonlinearities and fast changing operational conditions, is by modelling them as a *hybrid dynamical systems*, whose state may jump as well as vary continuously. These jumps between the different models can be used to represent drastically change in the structures behaviour (such as proposed in this paper active bracing) while the dynamic between the jumps is used to model the system in the presence of relatively constant conditions:

$$\begin{aligned}\mathbf{x}(k+1) &= \mathbf{F}(m(k+1))\mathbf{x}(k)+\mathbf{G}(m(k+1))\mathbf{u}(k)\\ &\quad +\mathbf{T}(m(k+1))\boldsymbol{\xi}(k)\end{aligned} \tag{9}$$

$$\mathbf{y}(k)=\mathbf{H}(m(k))\mathbf{x}(k)+\boldsymbol{\eta}(k)$$

The approach assumes that this model sufficiently accurately describes the system. The system's mode sequence is assumed to be a first order Markov chain with transition probabilities

$$P\{m_j(k+1) \mid m_i(k)\} = \pi_{i,j}(k) \tag{10}$$

with

$$\sum_j \pi_{i,j} = 1 \tag{11}$$

Further the Multiple model (MM) method, assumes that the set of N models has been set up to approximate the hybrid system by the following N pairs of equations:

$$\mathbf{x}(k+1) = \mathbf{F}_j\mathbf{x}(k) + \mathbf{G}_j\mathbf{u}(k) + \mathbf{T}_j\boldsymbol{\xi}(k) \tag{12}$$

$$\mathbf{y}(k) = \mathbf{H}_j\mathbf{x}(k) + \boldsymbol{\eta}(k)$$

for $j = 1, \cdots, N$

Each pair of equations corresponds to a particular working regime. Collection of all these models form a set M, which will be refer to as a model set.

4.3 *Adaptive control – supervisor design*

The problem of hybrid system control is usually solved by hypothetical tests for selecting of the most appropriate model from the model set M. Afterward it is supposed that selected model is the real one and the structural control is computed according to the selected model. The main drawback of such approach is that it allows only hard decision, i.e. only one structure can be chosen at a given moment of time. Sometimes this is not enough for qualitative control. For example, this method does not give good representation of working regimes between the modelled ones. Of course the model set can be extended by adding new modes to it, but this is not a solution of the problem. If the models are very close to each other problems with the statistical testing may occur. Another drawback of this approach is the jump of the control signal at the moment when the control system switches from one model to another. In this investigation is suggesting an approach for solving this problem. The task is to develop methods for soft decision. These methods use convex combination of the models. By doing so the control action is smooth and there are no jumps.

One way to solve this problem is by extension of the multiple model set to linear differential inclusions. This is a much more general class of non-linear systems. Considering the model set M, the linear differential inclusions are defined as the set of all systems that are a *convex combination* of the N models in M:

$$M : \mathbf{y}(k) = \sum_{l=1}^{n} \boldsymbol{\mu}_l(k)\mathbf{y}_l(k), \tag{13}$$

with

$$\sum_{l=1}^{n} \boldsymbol{\mu}_l(k) = 1. \tag{14}$$

where μ is the vector containing the probabilities for each of the modes. Below this vector is called the mode probability vector. The probabilities in μ provides the certainty that this model is the true one. Probability 1 means that the load condition of the system is exactly the same as modelled for this particular model. Probability close to 0 means, that the load condition in the system is very different from the modelled ones. For the adaptation purpose, the mode probabilities have to be calculated for each time instant.

A bank of $\mathbf{H}_2$ (see section 4.5) controllers have been created, in such a way that there is a separate controller for each model (in model set M). It is proposed that the final control signal to be weighted sum from the control signals, obtained from the individual controllers. For the weights is suggested the mode probability vector:

$$\mathbf{o}(k) = \sum_{l=1}^{N} \boldsymbol{\mu}_l(k)\mathbf{w}_l(k), \tag{15}$$

where the **o** is the input to the actuator for structural control and $\mathbf{w}_l$ are control signals computed from the individual controllers.

Then the adaptive control of the system break down into computing of the probabilities for each model from model set M.

4.4 *Residual evaluation*

The residual evaluation is performed by using standard quadratic programming optimization procedure (Ichtev et al. 2002). As initial model probabilities are used the probabilities from the previous iteration. For the first iteration it is assumed that there is no earthquake. The minimization is based on the following criteria

$$\min_{\boldsymbol{\mu}(k)}\left[\left(\mathbf{Y}_m(k) - \mathbf{Y}_c(k)\boldsymbol{\mu}(k)\right)^T\left(\mathbf{Y}_m(k) - \mathbf{Y}_c(k)\boldsymbol{\mu}(k)\right)\right] =$$
$$\min_{\boldsymbol{\mu}(k)}\left[\boldsymbol{\mu}(k)^T\mathbf{Y}_c(k)^T\mathbf{Y}_c(k)\boldsymbol{\mu}(k) - 2\mathbf{Y}_m(k)^T\mathbf{Y}_c(k)\boldsymbol{\mu}(k)\right] \tag{16}$$

subject to constraints:

$$\sum_{j=1}^{N} \boldsymbol{\mu}_j(k) = 1, \quad 0 \le \boldsymbol{\mu}_j(k) \le 1 \tag{17}$$

for $j = 1, 2, \cdots, N$. Here $\mathbf{Y}_m$ are measured outputs of the system, $\mathbf{Y}_c$ are predicted outputs of all models in N and μ is the vector which contains the mode probabilities for each of the models:

$$\mathbf{Y}_m(k) = [\mathbf{y}_1(k) \quad \mathbf{y}_2(k) \quad \cdots \quad \mathbf{y}_n(k)]^T \tag{18}$$

$$\boldsymbol{\mu}(k) = [\boldsymbol{\mu}_1(k) \quad \boldsymbol{\mu}_2(k) \quad \cdots \quad \boldsymbol{\mu}_n(k)]^T \tag{19}$$

$$\mathbf{Y}_c(k) = \begin{bmatrix} \mathbf{y}_{11}(k) & \mathbf{y}_{12}(k) & \cdots & \mathbf{y}_{1N}(k) \\ \mathbf{y}_{21}(k) & \mathbf{y}_{22}(k) & \cdots & \mathbf{y}_{2N}(k) \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{y}_{n1}(k) & \mathbf{y}_{n2}(k) & \vdots & \mathbf{y}_{nN}(k) \end{bmatrix} \tag{20}$$

The idea is that the difference between the systems output and calculated values from the models should be minimal. In fact this is minimization of the square error. This solution is chosen because only the absolute value of the error is important. To the smaller values of error corresponds greater probability.

The principle of the optimization remains the same when are used states instead of outputs. When the mode probability estimation is performed for a current time instant, momentarily problems may occur. One of the problem comes from the fact that the noise presence in real life systems. In case of strong noise the residuals for the correct model may become equal or even bigger than other residual(s). Another problem may occur if the system is operating between two models. In this situation the decision for the right model can be difficult.

One way to solve this problem is to use moving time window. This will slow down the mode estimation algorithm, but will solve the problem with the momentarily discrepancies. Suggested approach is preferred in this investigation. In (Ichtev & Puleva 2008) is proposed moving average of the mode probability.

For a particular working configuration no more that two models can be selected. Otherwise the optimization procedure can not estimate the mode probabilities.

4.5 *Design for local H2 controllers*

Consider the general block diagram description of the control problem given in Figure 2. Here **y** is the measured output vector of structural responses, **z** is the vector of structural responses which are desired to control, **u** is the control input vector, and **d** is the input excitation vector. For this experiment the measured output vector **y** includes the actuator displacement and the accelerations of each floor of the test structure.

The regulated output vector **z** may consists of any linear combination of the states of the system and components of the control input vector **u**, thus allowing a broad range of control design objectives to be formulated through appropriate choice of elements of **z**. Weighting functions can be added to elements of **z** to specify the frequency range over which each element of **z** is minimized.

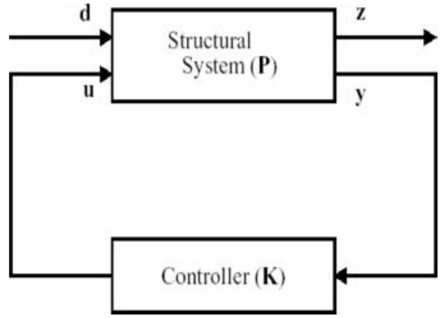

Figure 2. Principle structural control block diagram.

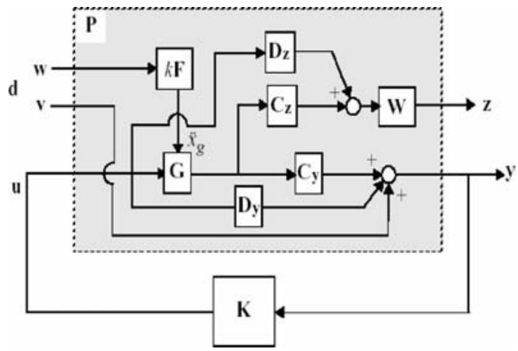

Figure 3. Structural control block diagram.

The structural control block diagram in Figure 3 contains the test structure, filters and weighting functions in the frequency domain.

The task here is to design a controller **K** that stabilizes the system and, within the class of all controllers which do so, minimizes the $\mathbf{H}_2$ norm of the transfer function matrix $\mathbf{H}_{zd}$ from **d** to **z**, where the $\mathbf{H}_2$ norm is given according to (21).

$$\|\mathbf{H}\|_2 = \sqrt{trace\left\{\frac{1}{2\pi}\int_{-\infty}^{\infty} \mathbf{H}^*(j\omega)\mathbf{H}(j\omega)d\omega\right\}} \tag{21}$$

To obtain the transfer function $\mathbf{H}_{zd}$, we refer to Figure 2 and partition the structures transfer function matrix **P** into its components, as shown in (22).

$$\mathbf{P} = \begin{bmatrix} \mathbf{P}_{zd} & \mathbf{P}_{zu} \\ \mathbf{P}_{yd} & \mathbf{P}_{yu} \end{bmatrix} \tag{22}$$

The matrix **P** includes the weighting functions employed in the control design and is assumed to be strictly proper. The overall transfer function from **d** to **z** is written as (23).

$$\mathbf{H}_{zd} = \mathbf{P}_{zd} + \mathbf{P}_{zu}\mathbf{K}(\mathbf{I} - \mathbf{P}_{yu}\mathbf{K})^{-1}\mathbf{P}_{yd} \tag{23}$$

Consider a structure experiencing a one-dimensional earthquake excitation $\ddot{x}_g$ and active control input **u**. The structural system, which includes the structure and the active bracing system, can be represented in state space form as (24) and (25)

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u} + \mathbf{E}\ddot{x}_g \tag{24}$$

$$\mathbf{y} = \mathbf{C}_y\mathbf{x} + \mathbf{D}_y\mathbf{u} + \mathbf{v} \tag{25}$$

$$z = \mathbf{C}_z\mathbf{x} + \mathbf{D}_z\mathbf{u} + \mathbf{v} \tag{26}$$

where **x** is the state vector of the system, **y** is the vector of measured responses, and **v** represents the noise in the measurements. A detailed block diagram representation of the system given in (24) and (26) is depicted in Figure 3, where the transfer function **G** is given by (27).

$$\mathbf{G} = \mathbf{C}(s\mathbf{I} - \mathbf{A})^{-1}[\mathbf{B}\ \mathbf{E}] = \mathbf{C}(s\mathbf{I} - \mathbf{A})^{-1}[\mathbf{B}\ \mathbf{E}] = [\mathbf{G}_1\ \mathbf{G}_2] \tag{27}$$

The filter **F** shapes the spectral content of the disturbance modelling the excitation, $\mathbf{C}_y$ and $\mathbf{C}_z$ are constant matrices that dictate the components of structural response comprising the measured output vector **y** and the regulated response vector **z**, respectively. The earthquake filter F was modelled based on the Kanai-Tajiami spectrum.

The matrix weighting functions $\mathbf{W}_1$ and $\mathbf{W}_2$ are generally frequency dependent, with $\mathbf{W}_1$ weighting the components of regulated response and $\mathbf{W}_2$ weighting the control force vector **u**.

The input excitation vector **d** consists of a white noise excitation vector **w** and a measurement noise vector **v**. The scalar parameter k is used to express a preference in minimizing the norm of the transfer function from **w** to **z** versus minimizing the norm of the transfer function from **v** to **z**. For this block diagram representation, the partitioned elements of the system transfer function matrix **P** in (22) are given by (28)–(31).

$$\mathbf{P}_{zd} = \begin{bmatrix} \mathbf{P}_{z_1w} & \mathbf{P}_{z_1v} \\ \mathbf{P}_{z_2w} & \mathbf{P}_{z_2v} \end{bmatrix} = \begin{bmatrix} k\mathbf{W}_1\mathbf{C}_z\mathbf{G}_2\mathbf{F} & 0 \\ 0 & 0 \end{bmatrix} \tag{28}$$

$$\mathbf{P}_{zu} = \begin{bmatrix} \mathbf{P}_{z_1u} \\ \mathbf{P}_{z_2u} \end{bmatrix} = \begin{bmatrix} \mathbf{W}_1\mathbf{C}_z\mathbf{G}_1 \\ \mathbf{W}_2 \end{bmatrix} \tag{29}$$

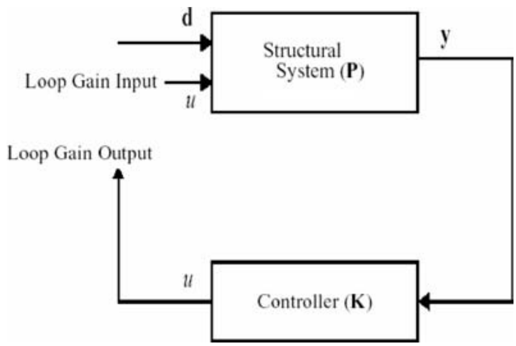

Figure 4. The loop gain transfer function.

$$\mathbf{P}_{yu} = \mathbf{C}_y\mathbf{G}_1 + \mathbf{D}_y \tag{30}$$

$$\mathbf{P}_{yd} = [\mathbf{P}_{yw}\quad \mathbf{P}_{yv}] = [k\mathbf{C}_y\mathbf{G}_2\mathbf{F}\quad \mathbf{I}] \tag{31}$$

Equations (28)–(31) can then be substituted into (23) to yield an explicit expression for $\mathbf{H}_{zd}$.

The loop gain transfer function was examined in assessing the various control design. Here, the loop gain transfer function is defined as the transfer function of the system formed by breaking the control loop at the input to the system, as shown in Figure 4.

Using the plant transfer function given in (30), the loop gain transfer function is given as (32).

$$\mathbf{H}_{loop} = \mathbf{K}\mathbf{P}_{yu} = \mathbf{K}(\mathbf{C}_y\mathbf{G}_1 + \mathbf{D}_y) \tag{32}$$

The loop gain transfer function from the actuator command input to the controller command output was calculated for connecting the measured outputs of the analytical system model to the inputs of the mathematical representation of the controller.

The loop gain transfer function was used to provide an indication of the closed-loop stability when the controller is implemented on the physical system. For this purpose, the loop gain should be less than one at the higher frequencies where the model poorly represents the structural system (i.e., above 35 Hz). Thus, the magnitude of the loop gain transfer function, at higher frequencies, should roll-off steadily and be well below unity. Herein, a control design was considered to be acceptable for implementation if the magnitude of the loop gain at high frequencies was less than −5 dB at frequencies greater than 35 Hz.

5 EXPERIMENTS

5.1 *Experimental setup*

The simulation are carried out with a model of five storey building with sensor network for detection the accelerations, active bracing systems and semi-active hydraulic dampers for each floor, except the last one as shown on Figure 5.

The simulator used for this investigation consists of a hydraulic actuator servo/valve assembly that drives a 122 cm × 122 cm aluminium slip table mounted on high-precision, low-friction linear bearings. The capabilities of simulator are: maximum displacement ±5 cm, maximum velocity ±90 cm/sec, and maximum acceleration ±4 g/s with a 450 kg test load. The operational frequency range of the simulator is nominally 0–50 Hz. The test structure, shown on Figure 5, was constructed from steel with a height of 280 cm. The floor masses of the model weighted a total of 340 kg, distributed evenly between the five floors. The time scale factor was 0.2 making the natural frequencies of the model approximately five times those of the prototype.

A simple implementation of an active bracing system was placed on each floor of the structure model for control purposes. The active bracing system was driven of a high pressure hydraulic actuator attached to each end of the piston rod. A Duvall servo valve was employed that has an operational frequency range of 0–45 Hz. This hydraulic actuator was fitted with low friction Teflon seals to reduce nonlinear frictional effects. The total mass of the structure including the frame and the active bracing system is 440 kg. As the hydraulic actuators are inherently open loop unstable, position feedback is employed to stabilize the control actuator. The position of the actuator is obtained with a linear variable differential transformer rigidly mounted between the piston rod and the fifth floor.

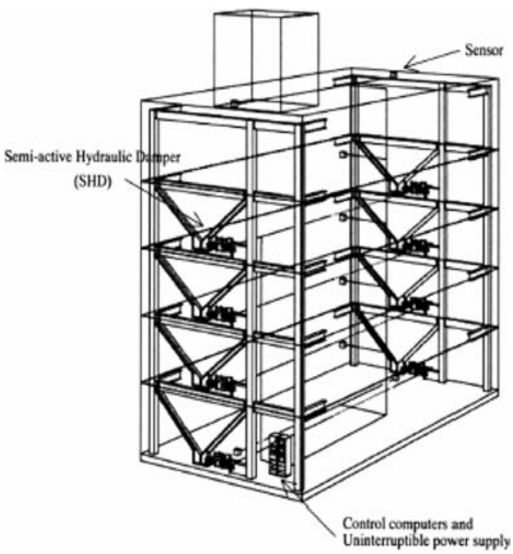

Figure 5. Structural control system with semi-active hydraulic dampers.

As shown in Figure 5 accelerometers positioned on the each floor of the structure measured the absolute accelerations of the model, and an accelerometer located on the base measured the ground excitation. The displacement of each floor is detected by sensors and measured using the linear variable differential transformer.

To develop a high quality, control-oriented model, an eight channel data acquisition system consisted of eight Syminex XFM82 3 decade programmable anti-aliasing filters are employed. The data acquisition system consists as well of an Analogical CTRTM-05 counter-timer board and the Snap-Master software package. The XFM82 offer programmable pre-filter gains to amplify the signal into the filter, programmable post-filter gains to adjust the signal so that it falls in the correct range for the A/D converter, and analog anti-aliasing filters which are programmable up to 25 kHz.

The implementation of the digital controller was performed using the Spectrum Signal Processing Real-Time Signal Processor (DSP) System. The on-board A/D system has two channels with 16 bit precision and a maximum sampling rate of 200 kHz. The two D/A channels, also with 16 bit precision, allow for even greater output rates so as not to be limited.

5.2 *Experimental determination of the transfer function*

Methods for experimental determination of transfer function break down into two fundamental types: swept-sine and the broadband approaches using fast Fourier transforms. Both methods can produce accurate transfer functions estimates. The swept-sine approach is rather time-consuming, because it analyzes the system one frequency at a time. The broadband approach estimates the transfer function simultaneously over a band of frequencies. The first step is to independently excite each of the system inputs over the frequency range of interest. Exciting the system at frequencies outside this range is typically counter productive; thus the excitation should be bound limited (e.g., pseudo-random). Assuming the two continuous signals (input $u(t)$ and output $y(t)$) are stationary, the transfer function is determined by dividing the cross spectral density of the two signals S_{uy} by the auto-spectral density of the of the input signal S_{uu} as (33).

$$H_{yu}(j\omega) = \frac{S_{uy}(j\omega)}{S_{uu}(\omega)} \qquad (33)$$

However, experimental transfer functions are usually determined from discrete-time data. The continuous time records of the specified system input and the resulted responses are sampled at N discrete-time intervals with an A/D converter yielding a finite duration, discrete-time representation of each signal $u(nt)$ and $y(nt)$, where T is the sampling period and $n = 1, 2, \ldots, N$. For the discrete case (33) can be presented as (34).

$$H_{yu}(jk\Omega) = \frac{S_{uy}(jk\Omega)}{S_{uu}(k\Omega)} \tag{34}$$

where $\Omega = \omega_S/N$, ω_S is the sampling frequency, $k = 0, 1, ..N - 1$. The discrete spectral density functions are obtained via standard digital signal processing methods. This frequency transfer function can be thought of as frequency sampled version of the continuous transfer function in (33).

In practice, one collection of samples of length N does not produce very accurate results. Better results are obtained by averaging the spectral densities of a number of collections of samples of the same length. Given that M collection of samples are taken the equations for averaged functions are (35),

$$\begin{aligned} \bar{S}_{uu}(k\Omega) &= \frac{1}{M}\sum_{i=1}^{M} S^i_{uu}(k\Omega) \\ \bar{S}_{uy}(j\Omega) &= \frac{1}{M}\sum_{i=1}^{M} S^i_{uy}(jk\Omega) \\ \bar{H}_{yu}(jk\Omega) &= \frac{\bar{S}_{uy}(jk\Omega)}{\bar{S}_{uu}(k\Omega)} \end{aligned} \tag{35}$$

where S^i denotes the spectral density of the i-th collections samples and the over bar represents the ensemble average. Note, that increasing of number of samples N, increases the frequency resolution, but does not increase the accuracy of the transfer functions. Only increasing the number of averages M will reduce the effects of noise and nonlinearities in the results. To determine the discrete spectral density functions in (35) a finite number of samples are acquired and a fast Fourier transform is performed.

The transfer functions from the ground accelerations to each of the measured responses were obtained by exciting the structure with band-limited white noise ground acceleration (0–50 Hz) to the actuator command while the ground was held fixed.

The next step in the system identification procedure is to model the transfer functions as a ratio of two polynomials in the Laplace variable s. This task was accomplished via a least squares fit to the ratio of numerator and denominator polynomials, evaluated on the $j\omega$ axis, to the experimentally obtained transfer functions. The algorithm requires the user to input the number of poles and zeros to use in estimating the transfer function, and then determines the location for the poles/zeros and the gain of the transfer function for a best fit.

6 EXPERIMENTAL RESULTS

Two series of experimental tests were provided to evaluate the performance of the controllers that were designed. First a broadband signal (0–50 Hz) was used to excite the structure and root mean square responses were calculated. In the second series of the tests an earthquake-type excitation was applied to the structure and peak responses were determined.

The results of two representative control designs are given, where the Controller A was designed by placing an equal weighting on the absolute accelerations of each floor of the structure. The second controller (Controller B) was designed using the same weighting matrix as Controller A, but in addition used loop shaping techniques to roll-off the control effort at higher frequencies. The analytical transfer functions for these two controllers are compared to the experimentally obtained transfer functions, presented on Figure 6 and Figure 7.

The performance of each controller was tested by exciting the structure with broadband ground acceleration (0–100 Hz) and the values of the responses for the uncontrolled and controlled configurations of the structural system are shown in Table 1. The results include responses for the relative displacements and the absolute accelerations of each

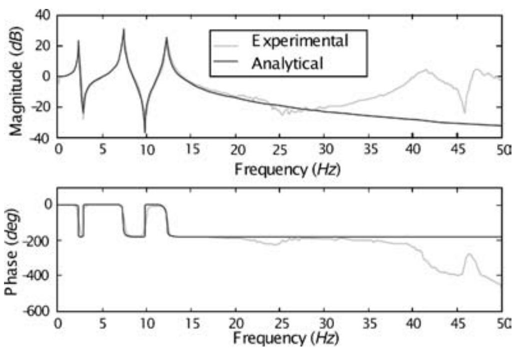

Figure 6. Transfer function for Controller A.

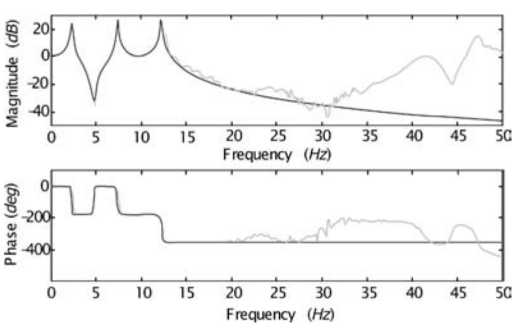

Figure 7. Transfer function for Controller B.

Table 1. Response of controlled system to broadband excitation.

	x_p cm	$\ddot{x}_{a_1}$ cm/s^2	$\ddot{x}_{a_2}$ cm/s^2	$\ddot{x}_{a_3}$ cm/s^2	$\ddot{x}_{a_4}$ cm/s^2	$\ddot{x}_{a_5}$ cm/s^2
Uncontrolled	0,682e^{-2}	148,4	153,5	164,6	203,8	232,0
Zeroed-Control	0,204e^{-2}	118,7	125,8	139,3	156,8	168,5
Controlled	0,327e^{-2}	98,2	96,3	90,4	88,4	86,8

floor. Notice that with control, the absolute accelerations of each of the floors are reduced significant, over the uncontrolled responses, and the first floor displacement is reduced by 95,6%.

From the table is seen that for controlled structure the measured values for absolute acceleration decrease with increasing of the floor. For structure without control the values of absolute acceleration increase with increasing of the floor.

7 CONCLUSIONS

An approach for multiple model active/semi-active structural control realized with a number of active bracing control systems, where each system corresponds to different device or combination of devices for structural control is proposed.

Proposed acceleration feedback control strategies were implemented and verified on a five-storey single-bay test structure controlled by semi-active hydraulic damper controller.

The effects on actuator dynamics and control structure interaction were incorporated into the system identification procedure. Under the broadband excitation the semi-active hydraulic damper controller was able to achieve approximately 80% reduction of acceleration responses and a significant response reduction was achieved in all three modes of the system. When excited by an earthquake disturbance, the peak response reduction of the top floor acceleration was 68%. The received results show that acceleration feedback control strategies should be regarded as viable and effective for mitigation of structural response due to seismic excitations.

ACKNOWLEDGEMENTS

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Models and ICT applications for resource efficiency

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Use of BIM and GIS to enable climatic adaptations of buildings

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SUMMARY: Analysis of climatic adaptation of buildings and their near environment is only in small degree assessed by experts. There is a need for better access to relevant information, in right time and cost, and to develop rule-based methods for automatic assessment building or building parts. Use of Building Information Models (BIM) in rule-based programs access information trough the non-proprietary IFC-file format. This will set enable more geographic diversified adaptations of buildings. The quality of the assessment methods in the software tools can be accredited by standardization organizations. This can be used for certification and/or for documentation to the building owner to get documentation in what degree the project goals is achieved. The assessment method in the software tools can be developed by using the IDM method (Information Delivery Manual) in the buildingSMART/IFC/BIM concept. An increased use of quantitative analyzes will influence the design process and make it possibly to both reduce climatic related damages on buildings, improve user quality, and improve the balance between climatic adaptation demands with numbers of other demands.

1 THE NEED FOR BETTER CLIMATIC ADAPTATION OF BUILDINGS

1.1 *Climate induced damages*

The need for increased focus on climatic adaptation is illustrated by the fact that more than 75% of building defects are induced by climatic strain, with moisture as the main source of the defects. A large share of these defects originates in early stages of the construction process. Findings suggest that as much as 40% of building defects in Norway can be related to mistakes or omissions in the design process. This is also in good agreement with corresponding investigations or sources of information in other European countries. (Ingvaldsen, T., 1994, 2001). Experiences and registrations from Lisø et al. (2006a) demonstrate an evident need of preventive measures in the planning and design phases of the construction process to reduce the extent of process induced moisture defects and the impact on building quality, building lifetime and users' health etc.

1.2 *Climatic information and declaration*

Imprecise descriptions of the climate as "windy places", "cold areas", "normal climate", "weather exposed areas", "areas with much driving rain", and "exposed costal areas", does not give adequate basis for geographic diversified climatic adaptation of buildings. But these descriptions are often used in study books and guides. (Kvande, 2007). Climatic adaptation beyond regulations and demands easily become downgraded in competition with other demands (Eriksen et. al. 2007).

Seemingly the clients' lack of requirements addressing moisture issues may be in conflict with the provisions of the Norwegian planning and building legislation. (Øyen, 2007). A better system for addressing clients' requirements is therefore needed. This system can also be used for documentation of which degree the clients' requirement is achieved. Investigations performed by Lisø et al. (2006) show that as much as 20% of the construction process induced building defects can arise due to alterations of client requirements or reductions of the budget. Sikander & Grantén (2003) performed a survey accomplished among builders/clients and construction project managers and found that two out of three clients or building administers report that moisture safety related requirements are not addressed specifically or not addressed at all in refurbishment projects or new construction projects. They state clearly that the property developer plays a key role in initializing a decrease of moisture induced building defects in a construction project. They stress the importance of a close follow-up of preventive measures by careful supervision and control. According to Dragne (2008) the precipitation decreased with 18% from 1900 to now. Prediction show that this increase will continue.

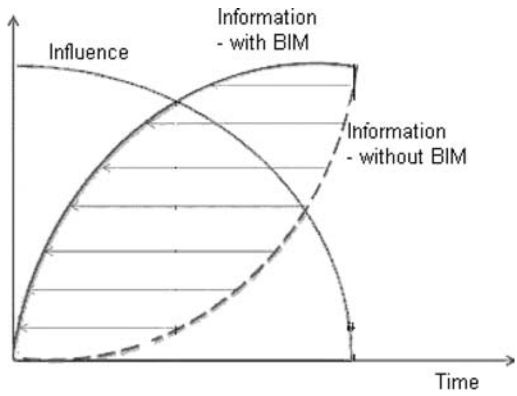

Figure 1. Illustration of the connection between influence and available information. (Bentley, 2008). The figure is modified with text "with/without BIM".

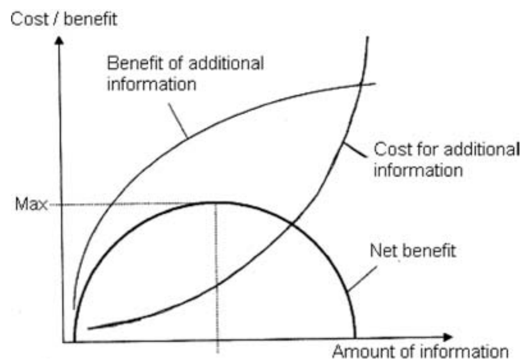

Figure 2. Illustration of cost and benefit of information in a project. (Samset, 2001).

The Norwegian architect Jonassen (2008) state that the focus on climate adaptation in education is too low, and that there are several examples of bad or missed adaptation in several building projects in Oslo (Norway). One extenuating circumstance for this is the lack of proper ICT tools.

Climatic information is often presented in different scales as micro-, meso-, macro- and global scale. Smaller scale usually results in more data to process, and will for traditional methods be unwieldy to use. An example of a widely used system is the Köppens classification system for climate. It is based on grouping a lot of temperature and precipitation data into a code that is used for finding building solutions who correspond with this code. (Wolleng, 1979). The BIM concept enables processing of large amount of data and can therefore be used on the basis data.

It is also important to be aware of that there are several relevant climatic parameters which are derived or have not been collected. Petersen (1978) gives radiation of sun, humidity in air, frequency of driving rain as examples. An other relevant parameter is snow accumulation, where the combination of precipitating snow and wind is important. This is often more relevant for building adaptation than the traditional measurements of snow and precipitation (Tveito, 2004).

1.3 *Possibilities for adaptation in planning*

The design process is iterative. Use of BIM/IFC offers these interactions possible with decreased time and costs due to more information and better exchange of data between different programs.

We want to point out the possibilities for influence that stands in the Front-end/Early Design phase. The importance of the interactivity in the design process is showed in figure 1. We see that the design process starts with high freedom to influence, but very little information. The possibilities to influence decrease rapidly. The BIM approach offers more information in an earlier phase than the traditionally.

A challenge in practical design is the cost and time to obtain information. Figure 2 shows that there is an optimum, and remove a misunderstanding that more information will give most positive value. This facts that some information in the front-end/early design phase is more important than more detailed information analyses in later phases.

The goal of focusing on the Front-end/Early Design (ED) view is to capture these in a comprehensive and computable exchange format to pass to downstream technologies such as design modeling, and engineering analysis technologies. It also provides the ability to compare several alternative designs for climatic adaptations and other best practice design (NBIMS, 2006b).

The groundwork for this interoperability is based on that the source for both BIM and GIS information is in a transparent and documented format, described in a standard. Use of ISO standard will ensure a documented format definition. This will not be possible with software developer defined data format.

2 BIM/GIS RELATED STANDARDS

2.1 *GIS – Geographical Information Systems*

The geographical sector has a long tradition for utilizing information technology. Geographical Information Systems (GIS) has a long history compared to BIM. We do therefore not describe GIS systems in this paper. ISO TC 211 has developed a series of 40 standards from ISO 191001:2000 to ISO 14141:2008 (TC 211, 2008) GIS related topics. The news is the

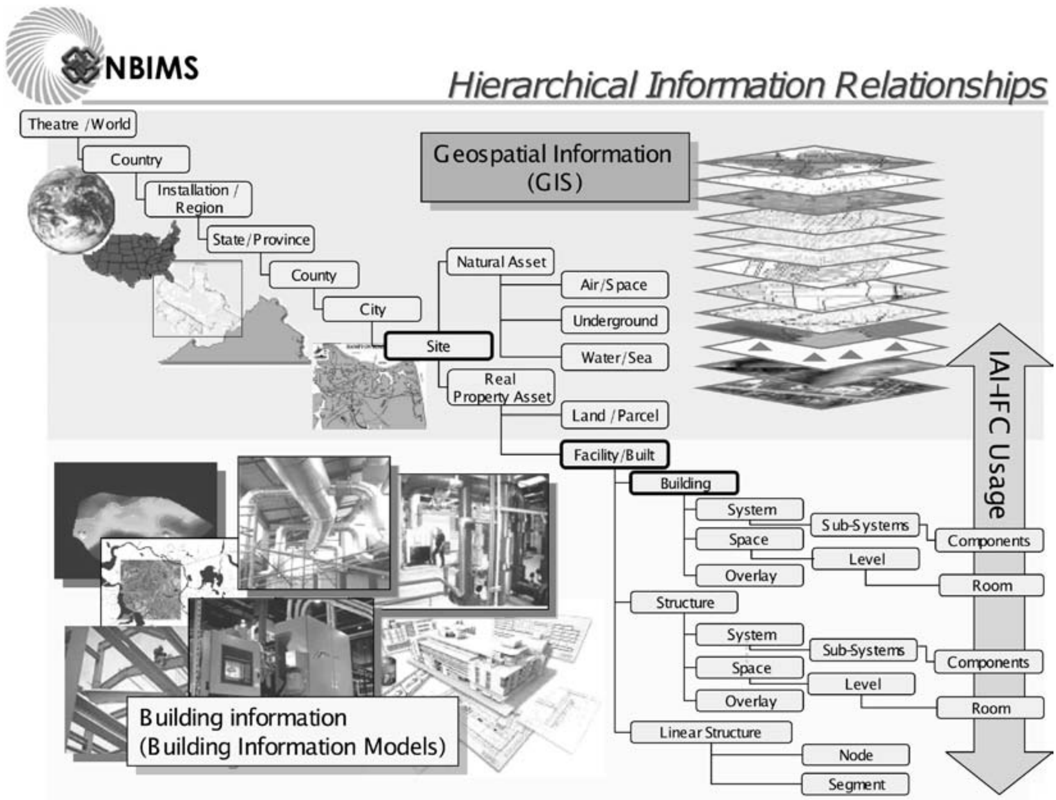

Figure 3. Hierarchical information relationship between GIS and BIM, National BIM Standard Presentation, (NBIMS, 2006a).

integrated use of BIM and GIS in the same design process.

2.2 *Integration of IFC and GIS in BIM*

The IFG project (IFG, 2008) was set out to define a bridge between BIM systems and GIS systems, see figure 3. This project does not seek to create complete geographical information inside IFC. Instead, it recognized the existence of other competent models for this purpose, notably the model underlying the Geographic Markup Language (GML) produced by the Open GIS Consortium (OGC). (IFG, 2008). GIS is widely used for distributing climatic data and is not further described here.

2.3 *The buildingSMART initiative*

buildingSMART is the branding for the three standards for object oriented data models in the AEC industry:

– IFC – is an exchange format that define how to share the information,
– IFC – is a reference library to define what information that are being shared
– IDM – Information requirements that define which information to share when
– (Haagenrud et al. 2008, Bell and Bjørkhaug 2006).

BIM is a widely defined concept. It is often used as a collective term for representation one or more of the buildingSMART models, mostly IFC. It is also used as a generally for object oriented data models of product models containing information and not only visualization of 3D building objects.

2.4 *IFC – Industry Foundation Classes*

Industry Foundation Classes (IFC) is a object oriented data model for management of information (IFC will always be a BIM, but a BIM does not have to be a IFC when it is in a proprietary file format. The IFC model use the file format extension *.ifc. IFC is an international open standard, ISO/PAS 16739, and is by this an open specification that is not controlled by a software developer. The numbers of IFC compliant program are increasing (ISG, 2008).

National administrative building related bodies in USA (GSA, www.gsa.gov/bim), Norway (Statsbygg, www.statsbygg.no), Finland (Senate Properties, http://www.senaatti.fi) and Denmark (DDB, http://www.detdigitalebyggeri.dk) are starting to demand BIM files as their project documentation instead (or in addition) to drawings and text.

The purpose of an IFC schema is to facilitate the exchange and sharing of information. This export and/or import functions can be implemented inen It is not a software in itself application, but may be used by a programming language and in this way be included in a software tool. The latest IFC version, IFC 2×3, was published in 2006. IFC version 2×3G (where G stands GIS) is available as an alpha release. The next IFC version 2×4 will have GIS and IFD support when planned released in september this year. (IAI, 2008b).

The increased focus on GIS is in the AEC industry is manifested in the "IFC for GIS project" (also known as IFG) initiated by the Norwegian State Planning Authority (Statens Bygningstekniske Etat) for processing of building applications. (IFG, 2008). The plan to use this for processing of building applications.

The new accreditation regime for IFC compliant software will be domain specific. Stangeland (2008). This demand s that the BIM/IFC model must contain complete information for defined tasks, e.g. quantity take of (QTO) or material information.

2.5 *IFD – International Framework for Dictionaries*

IFD is an abbreviation for International Framework for Dictionaries and is defined as a standard by ISO (ISO 12006-3:2007). It is useful for selection building products form databases, by using the properties to the building material/-part, and not only the product name. It is an open library, where concepts and terms are semantically described and given a unique identification number. Cooperating with IFC, the IFD standard will define the building information that is actually being exchanged. Thus, IFD is not an alternative, but a supplement to IFC. IFD is implemented in Norway, the Netherlands, Canada and USA. What is interesting about IFD is that it offers a 'Globally Unique Identifier', the so called GUID. The GUID can be compared with e.g. a personal identification number. When the user adds the properties in an IFD Library, it is done once (and for all) and may be used repeatedly and by other users as well (IFC, 2007).

Standards Norway (Standard Norge) (Mohus, 2006) has developed an IFD software program called "Library Propertylizer" for adding and maintaining content, and for assigning GUID to building products. IFD is flexible for adding information about new properties to building materials and parts. Assessment is based on this information content ("model richness"). IFD also supports semantic for multi-lingual use and for e-trade, also international.

2.6 *IDM – Information Delivery Manual*

IDM is an abbreviation for Information Delivery Manual and is under development as ISO/CD PAS 29481-1 by standardization group ISO TC59/SC 13. IDM is a framework for the electronic exchange of building specific information in the business processes and will specify:

- A defined activity in the building process (why it is relevant);
- Who are the actors involved in the activity (and the information flow between them);
- What is the information created and consumed in the activity;
- How this information should be supported by software solutions.

IDM (squares in right circle in fir. 4.) are specified part of the IFC model (left circle) Information Delivery Manual is an method for specifying information requirements for a specific task according to the IFC standard. Development of software and use of data bases for climatic assessment need only to follow the IDM specifications, and not implement the complete IFC standard to solve the task completely.

DM consists of three parts: i) Process Maps (PM) that capture the connection between exchange requirements and business processes. ii) Exchange Requirements (ER), defining the set of information within IFC that needs to be exchanged in a defined business requirement in the relevant stage of the building process, ii) Functional Parts (FP), being the technical content required by software developers to support the exchange requirements, and finally Different IDM can often use some of the same ER and FP. (IDM, 2008).

We have in figure 6. developed a Process Map for climatic assessment (certification) of how well the planned building (represented with a BIM, Building

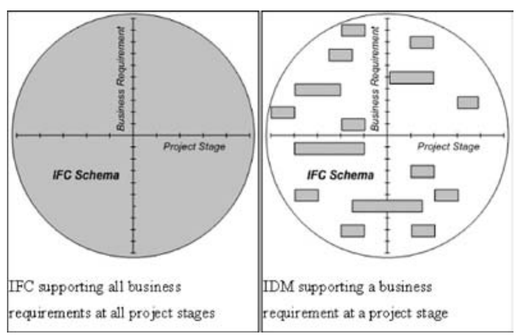

Figure 4. Illustration of the IDM as a part of the IFC schema (IAI, 2007).

Information Model, BIM) is adapted to the climatic conditions on the site. The BIM (from architect) is imported into the software for climatic assessment. This can be either separate software or a module in software program for multiple use, e.g. a CAD/BIM software. This software connects to external databases with information about climatic conditions on the site (geographic area).

2.7 *Combination of information and rules (codes)*

It is the combination of information from the BIM, defined by ER, and assessment methods, described by Verification Tests and Business Rules in figure 5

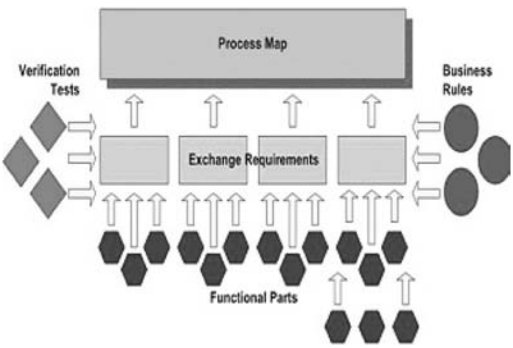

Figure 5. Schematic design of IDM components. (Wix 2006).

-that gives power to this approach. This gives basis for objective and approved assessment/certification of the building or building parts. Different certification criteria will demand development of new IDMs or adjustment of existing IDMs.

3 CLIMATIC ADAPTATION OF BUILDINGS

3.1 *Concept for automatic preparation of assessments*

Our intention is to offer a concept for automatic and rule-based assessment of the adaptation of buildings to their environment. The result can be used as certification for degree of climatic adaptation, similar for to the approach in the European Energy Performance of Buildings Directive (EPBD, 2008) or the EPD (Environmental Product Declaration) the marking system for white goods (EPD. 2008).

Table 1. Constraints for use of A (automatic) and M (manual) use of software for assessment of climatic information.

		User skill/interaction/ manipulation	
Constraints		Low	High
Preparation of information input	High	A	
	Low		M

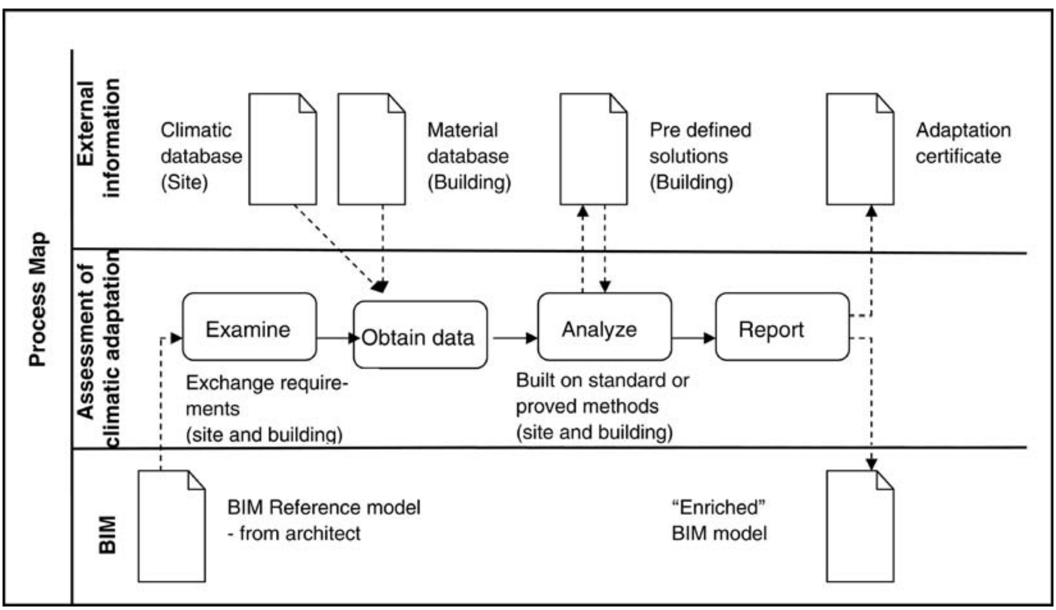

Figure 6. Process Map showing information flow for climatic adaptation.

Table 2. Summary of some relevant standards for climatic adaptation.

Climatic factor	Relevant standards
Building focus	
Driving rain	ISO/FDIS 15927-3 Hygrothermal performance of buildings – Calculation and presentation of climatic data – Part 3: Calculation of a driving rain index for vertical surfaces from hourly wind and rain data
Wind Comfort	NEN 8100, 2006. Netherlands Normalisation Institute, Wind comfort en wind danger in the built environment.
Indoor comfort	ISO 7730:2005 Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
Energy use	ISO 13790:2008 Energy performance of buildings – Calculation of energy use for space heating and cooling
Snow load	EUROCODE 1: EN 1991-1-3. Snow loads/ Actions on structures ISO 4355:1998 Bases for design of structures – Determination of snow loads on roofs
User focus	
Sun insulation	No known standard. Can cover assessment of sun insulation at a specific building part, e.g. balcony, at a defined time when it will be in use, e. from 5 pm to 9 pm. Is performed by visual inspection of the sun/shadow functions in BIM/CAD software

For a neutral assessment it is important to eliminate the possibility for user "manipulation" of the results. One can self see "evidence of manipulation" in sale prospect who which only shows sunny balconies (with happy people). But when you check, you see there are several balconies with no possibilities for sunlight due to surrounding obstacles.

This stand in relation to use of advanced software tools with lot of adjustment possibilities and where only the user and/or software developer know the information and methods who are used. Table 2 shows the difference between these two approaches.

A constraint for rule-based assessment is to use standardized methods accredited by standardization organizations (bodies), national or international, (CEN/ISO).

Figure 7 shows an assessment procedure for climatic adaptation of buildings. Information about the building and site is received from BIM/GIS model. This is supplemented with demands form the building owner (or architect). This is assessed against a predefined set of rules. If approved, one can get certificate with documentation of the degree of adaptation. If not approved, one can check against a database with predefined solutions. If on get no match, the building has to be re-designed.

We have found it useful to separate between the physical building (product) and the people who use the building at different times. This is done to highlight the schedule when the user wants to use the facility/building, e.g. the balcony.

Table 3 shows a summary over some different standards concerning climatic adaptations. The list is not complete, but indicates a wide range of standards for different purposes. This gives the foundation for developing rule-based assessment methods (formulas, algorithms) that can operate on information (data) from GIS and/or BIM files.

3.2 *Exemplification of climatic adaptations*

Use of rule-based assessments is showed by the following examples:

- Roof overhang – Sun radiation (vertical sun angle)
- Sun condition on balcony– Sun insulation (horizontal sun angle)
- Decay of wood – Scheffer index/Decay hazard maps

3.3 *Overhang sizing rules*

Assessment of the roof overhang to different sun angles defined by time of year and day can be used as an example of rule-based assessment. The overhang in figure 8. shows no direct sunlight in summer afternoon (17.00 on July 1.) In winter time one will have direct sunlight on the entire window in the winter afternoon (17.00 on January 1.).

The information about climate arises from GIS, and information about materials in building external wall arises from BIM/IFD. This objective considers being well suitable for rule-based assessment.

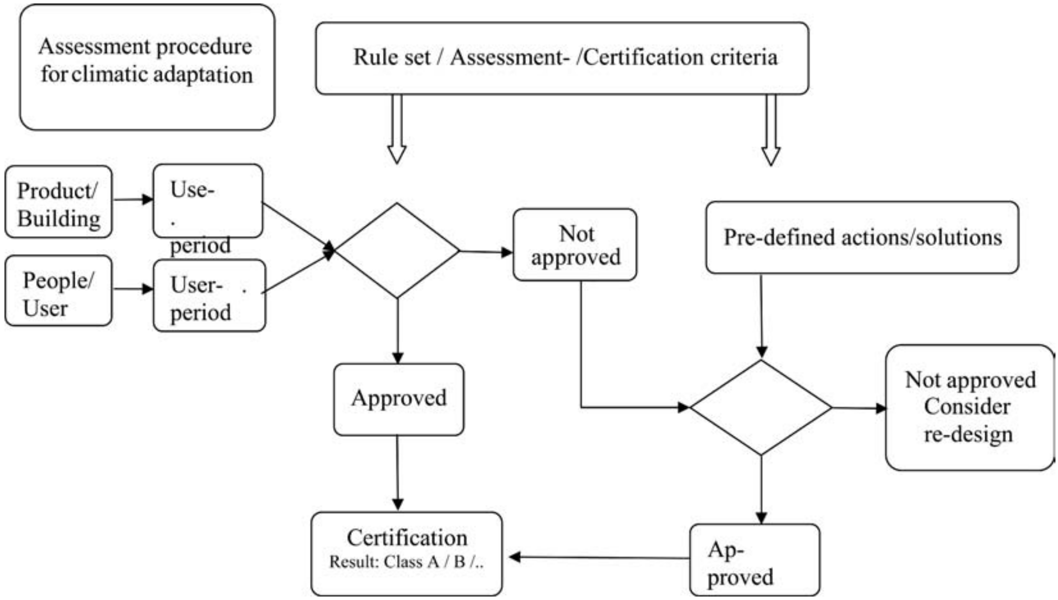

Figure 7. Assessment procedure for climatic adaptation of buildings.

Table 3. Recommended minimum roof overhang widths for one- and two-story wood frame buildings (Verrall and Amburgey, 1978).

Climate Index	Eave Overhang	Rake Overhang
Less than 20	N/A	N/A
21 to 40	30 cm/12″	30 cm/12″
41 to 70	45 cm/18″	30 cm/12″
More than 70	+60 cm/24″	+30 cm/12″

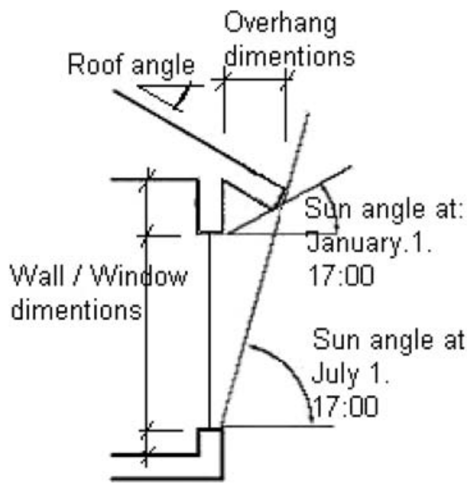

Figure 8. Assessment or roof overhang at different time of the year.

3.4 *Sun conditions on balcony*

Balcony placement – Sun insulation (hor. sun angle)The purpose here is to assess the usability of the balcony. To do this we must focus on the preferred user-period, who will be the time they intend to use the balcony. The user-period of a balcony will normally be in the afternoon – most attractive period. Afternoon can be defined as the 4 hour period form 17.00 to 21.00, and assessment can be done for each month in the summer period. This assessment method has similarities to the roof overhang, but has a user (human) oriented purpose instead of the physical building. Table 3 indicates the lack of standards for user oriented assessment.

This kind of assessment is normally done manually by visualization of sun/shadow of the building. As mentioned under 3.1 these analyzes/presentations can some times have limited credibility.

The information about sun positions arise from the site information (ifcSite) in the BIM and detection of the balconies derivatives for the room/space definition (ifcSpace) in the BIM. This objective considers being well suitable for rule-based assessment. Absence of standard assumes to be a challenge for common accepts of assessment results.

3.5 *Scheffer index*

Scheffer (1971) developed a formula that estimates the potential of a climate to promote decay of off-the-ground wood structures.

$$Scheffer\ index = \{\Sigma(jan\text{-}dec)\ [(9/5T-3)(D-3)]\}/30$$

T = monthly temperature in °C
D = # days /month, precipitation ≥ 0.1 mm.

The sum of products is arbitrarily divided by 30 to fall largely within the range of 0 −100. Areas rating less than 35 were considered the least favorable for decay; 30 to 65, intermediate; and more than 65, the most conducive to decay

We see that this has connection to assessment of sunlight described before in 3.3. An alternative solution is to use material or material treatment with higher resistance to decay. Assessment method for this is not described in this paper.

Maps for analysis for decay of wooden surfaces are developed for most countries. The Norwegian project “Klima 2000” (Klima, 2000) one have developed decay hazard map for Norway. Based on climate change scenario from Norway, Lisø et. al. (2006b) predicts an increased hazard in the future. Today’s constructions solutions do not take this into considerations. Underthun et. al. (2006) questions the climate adaptation of Norwegian prefab houses. They point out the technical solutions in the buildings are the same independent of where in Norway they are built.

The information about climate arises from GIS, and information about materials in building external wall arises from BIM. This objective considers being suitable for rule-based assessment. The challenge assumes to be a dynamic interaction between GIS and BIM data sources.

4 DISCUSSIONS

This paper is based on a conceptual approach on use of BIM/GIS technology for developing software for climatic adaptation of buildings.

The use of existing building code and standards in combination with BIM/GIS open up new opportunities for increased used of rule-bases assessment. But there is still some way to go for practical use.

Further research is recommended in two directions; technical and methodology. The technical approach should focus on development and testing of software for interoperability between BIM and GIS models. The data exchange should be based on IFC-format, and not use of middleware or proprietary solutions

The methodological approach should focus on developing rule-based assessment methods built on internationally agreed standards for certification of practical needs in the marked/for the client.

5 CONCLUSIONS

This study shows that the buildingSMART related standards IFC, IFD and IDM in combination with climatic information from GIS give possibilities for developing time and cost effective software for assessing the climate adaptation of buildings.

Uses of standard founded methods give credibility for automatic and rule-based assessments. This can be used for assigning certificate for the degree of adaptation and/or documenting that the clients request for climatic adaptation is achieved.

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Base case data exchange requirements to support thermal analysis of curtain walls

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ABSTRACT: This paper is concerned with data exchange requirements to support thermal analysis during the design phase of a building project, with specific reference to the representation of curtain wall elements. This is extremely critical for buildings in countries where the dominant energy use is for cooling because a large percentage of the cooling is attributable to fenestration. The IDM methodology is used as a test bed to model the business process to obtain the correct area of glazing in curtain walls for energy analysis. In this work, we have established a base case that imitates the current manual process used by thermal analysts in anticipation of developing a more accurate approach in the future. As a result of defining the information exchange requirements, it is expected that a significantly improved information model for curtain walling, fenestration and their constituent products will emerge, allowing for more practical and realistic component modeling and energy simulation by software applications.

1 INTRODUCTION

The traditional mode of information exchange in the architecture, engineering and construction (AEC) sector is by means of annotated 2D drawings. Increasingly, Building Information Modeling (BIM) is being adopted as a more effective mode of exchange because it allows for rich attribute data to be embedded in a single, unambiguous 3D representation of the design. Once accepted as a paradigm, BIM provides an integrated environment for performance based design (Fischer 2006) as well as promoting a collaborative design process better suited to the design of complex entities such as buildings (Lee et al. 2002). The Industry Foundation Classes (IFC) standard provides a robust schema for the representation of building models in general, but further research is needed in order to handle some specific types of architectural elements.

The work reported in this paper deals specifically with curtain wall design, exploring the information needed to support the interaction between the various consultants responsible for the design of these critical components of modern buildings. While Building Information Models offer great opportunities for sharing information, it has been found that current implementation by BIM vendors is insufficient to support the extent of fenestration detail required since the knowledge involved in understanding the energy impact of fenestration is complex. In particular, the representation of curtain walling is inconsistent amongst BIM vendors. This can be attributed to the fact that limited domain specific knowledge has yet been incorporated into BIM tools. This is supported by the position taken by Eastman (2006) that current BIM tools generally do not adequately represent component details. It is asserted that a thorough understanding of the exchange requirement between different disciplines has the potential to improve the quality of data sharing using BIM.

Given that the information needed is available and its quality appropriate, a recent study (Bazjanac & Kiviniemi 2007) shows that data transformation rules enable downstream processes to eliminate the need to manually re-create existing project information. More effective sharing of information through model based exchange has the potential to reduce the time for acquisition of building geometry. As indicated by Bazjanac (2001), manual interpretation of drawing is error prone and time consuming.

However, the mechanism available to formalize downstream user requirements is not well understood. This had led to deficiencies in the representation of some building elements by BIM applications using the IFC model specification. In particular, current representation for curtain walls is generally inadequate to effectively support energy analysis.

We argue that thorough understanding of downstream processes through proper description of use cases can improve the functionality of applications through the definition of data transformation rules.

It is suggested that the approach outlined in the Information Delivery Manual (IDM) is capable of communicating user requirements and can identify and construct user cases for solution providers to support processes in the AEC industry. For the purpose of this paper, we use the Business Process Modeling Notation (BPMN) to capture the requirements to determine the glazing area of curtain walls.

The purpose of the work reported in this paper is to establish a base case by modeling the information required to match current practice supporting the measurement of thermal performance of buildings that include curtain wall construction. Future work will investigate whether the use of BIM can lead to more accurate measurement of thermal performance and the semantic representation of curtain wall construction required to support that process.

2 RESEARCH CONTEXT

2.1 *Requirement capture*

It is widely accepted that methods to improve the quality of information generated in the requirements stage can result in higher quality software development. A process-centric approach is a data modeling method that uses a process model as means to collect user requirements. Even though many process models have been developed for the AEC industry, the diagramming methods generally used in their development, such as IDEF0 or UML, do not support the association of activities with information and communication. This can be attributed to the fact that there is a lack of formal methodologies to effectively capture user requirements. This position is supported by Eastman (2006) who argues that there is a lack of industry input and clearly defined use cases for software developers.

The process matrix (Gehre et al. 2002) is a process-centered methodology that associates information, communication and standardization requirement with process activities in the AEC industry. In essence, this provides an opportunity to consolidate domain knowledge and interactions between actors into a specification that is familiar to solution providers. In addition, it uses diagramming methods to integrate user requirements into the specification. It is envisaged that this development has the potential to improve the capability for information capture to facilitate downstream analysis.

The Information Delivery Manual (IDM) is an extension of the process matrix to support IFC development (Wix 2007). The Business Process Modeling Notation (BPMN) has been adopted as its means of process definition. It uses concepts to provide a bridge between meeting user requirements and certifying software through IFC model view definitions. Concepts are necessary for robust validation and implementation of data transformation rules. Figure 1 illustrates the notation adopted in IDM.

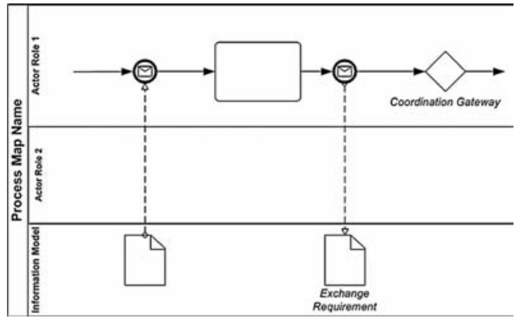

Figure 1. The BPMN notation used in IDM (Wix 2007).

By way of contrast, GTPPM (Lee 2006) is another formal methodology that has been used in the precast concrete industry to capture user requirements in the product model. This is derived directly from a process model developed by drawing on the knowledge of domain experts. Although this approach could inform our work, we have chosen to use the IDM methodology because it is supported by the IFC model server environment that will be used in the development of this work.

2.2 *Energy analysis and glazing area definition*

There has been an increasing reliance on building energy simulation applications to support the design of energy efficient buildings. Highly glazed facades have become a common design feature in new commercial buildings. As a large percentage of a building's cooling load is attributable to glazing, the ability to accurately predict the impact of solar radiation on glazing systems becomes critical. Accurate glazing area is required in order to predict the impact of solar radiation. In Australia, curtain wall design is a very common glazing system in office buildings.

One of the major impediments to the adoption of energy simulation tools is the process of specifying the building geometry to support the creation of an energy model. It is a time consuming and error prone process that occupies about 60% of the entire process time for energy analysis (Bazjanac 2001).

In current practice, glazing areas are derived manually from annotated 2D drawings, typically elevations that show the pattern of glazing across the facade. Figure 2 shows a typical elevation detail of a curtain wall represented as a 2D drawing. As can be seen, curtain walls consist of vision and spandrel panels supported

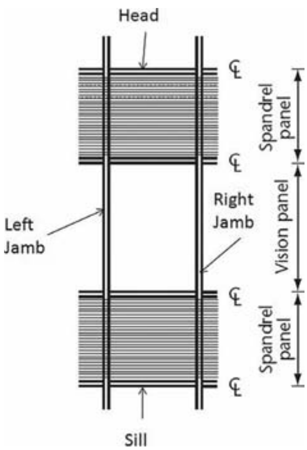

Figure 2. Typical annotation of curtain wall design found in 2D drawing (CSA, 2004).

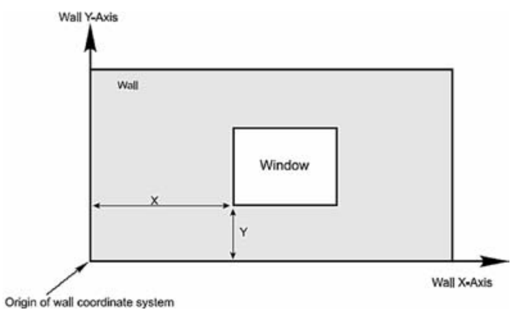

Figure 3. Locating a window in a wall (Hirsch, 2004).

in some kind of framing system. For the purpose of thermal analysis, it is generally assumed that the spandrel panels can be modeled as exterior wall elements while the vision panels are treated in the same way as windows in a punched wall construction (Ashrae et al. 2005). In this way, the energy analyst decomposes the spandrel and vision panels of curtain walls into exterior wall and window elements respectively in order to match the typical manner by which glazing is measured for the purpose of thermal analysis as shown in Figure 3.

Clearly, the information required to define accurate glazing area for energy analysis consists of window height and width as well as its position relative to its parent wall. The spandrel portion acts as the parent wall in the case of a curtain wall. As shown in Figure 2, these parameters can be easily derived from 2D annotated drawings as the spandrel panel is shaded differently from the vision panel.

As we migrate from paper to model based exchange, it is important to ensure that the quality and speed of acquiring this information from the model be improved. The ability to formally capture the process of deriving the size and position of vision panels from 2D drawings (Figure 2) and inputting appropriate attributes of these elements into an energy model is critical when managing the transition into model based exchange. However, it is critical for an energy analyst to understand what information is coming from BIM that is entered into the energy analysis software.

3 CURRENT IDM FOR ENERGY ANALYSIS

In this section, we outline the current IDM defined for thermal analysis by the IAI (IAI 2008). There are four parts to an IDM that are relevant to our discussion: a process map; a set of exchange requirements; functional parts and business rules. We will describe each of these components in turn, using the current definitions proposed by the IAI to illustrate the concepts and form the basis for our proposed extension to that IDM to support the base case representation of a curtain wall.

3.1 *Process map*

A Process Map is a collection of activities necessary to generate a business outcome. It provides both a graphical representation and a textual description of processes. It is developed by domain experts to ensure that it exists in a form that is useful and easily understood by end-users. Actors involved in a typical process are represented by horizontal “swim lanes” as shown in Figure 1. Typically, information is derived from the building information model to support downstream processes. Activities are represented by a rectangular box in a swim lane of the corresponding actor. When used in conjunction with the textual description, process maps provide an end user with information such as the project stages when information exchange is expected to happen, the objective, exchange requirements as well as the outcome of this business process. The notation allows non-atomic processes to be broken down into sub-processes by linking to a separate process map (as in Figures 4 & 5 and discussed in the following section).

3.1.1 *Current process map*

As stated earlier, the acquisition of accurate glazing area is an important user requirement for energy analysis. Figure 4 shows the current high level process map for energy analysis during the design stage as defined by the IAI. The diagram is generally fairly self-explanatory, showing the different actors and sequences of activities to be followed. Note that an atomic activity is one that does not need to be broken down, while a process step that can be collapsed

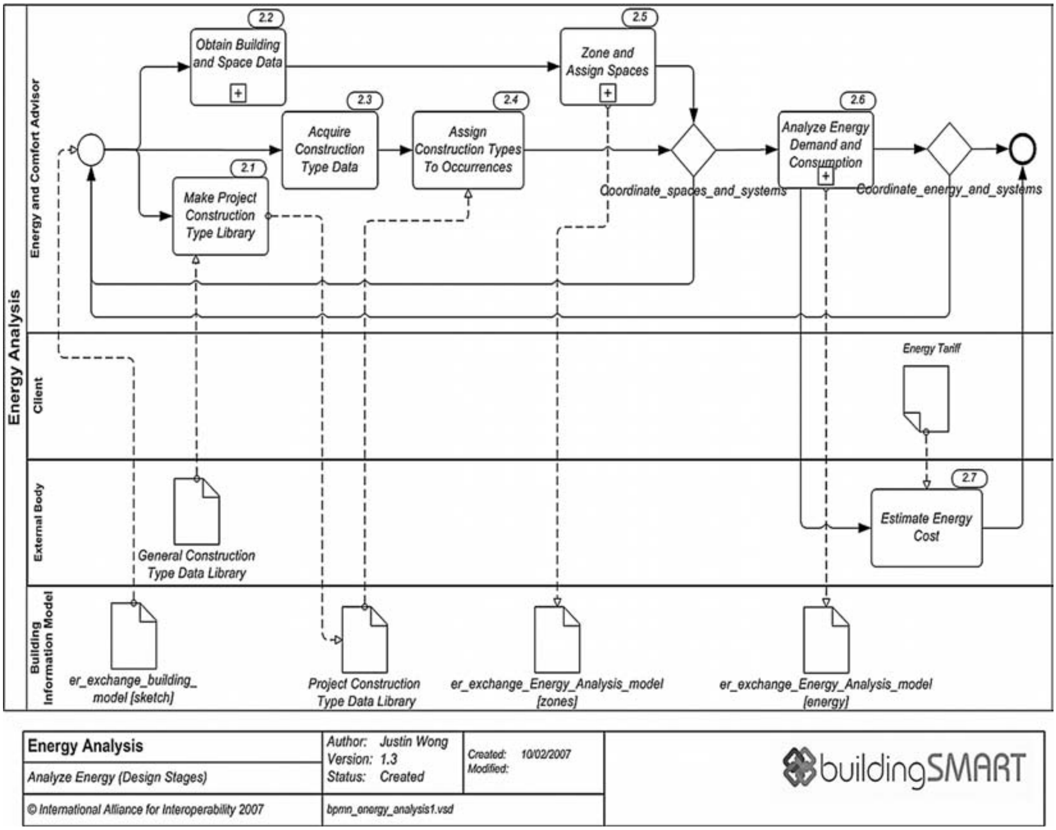

Figure 4. Current process Map for energy analysis.

into a set of sub-processes is indicated by a plus sign at the bottom of the square, signifying that a separate diagram is available showing how that process is broken down.

We will focus our attention on capturing this user requirement during the design process when an energy analyst is required to provide performance feedback to the designer.

We focus our review on the work of the thermal analyst, and specifically on activity 2.2, "Obtain Building and Space Data" in the current process map. Our aim is to determine if the glazing area of a curtain wall can be derived in this process step. Being a collapsed sub-process, we need to also examine the expanded process for "Obtain Building and Space Data" (Figure 5).

As shown in Figure 5, the activity "Obtain Building and Space Data" has been expanded into four parallel atomic processes. Within this expanded activity, the process of acquiring building geometry has been represented by an atomic activity named "Derive Building Information". In a traditional work process, this geometric information is measured off a 2D drawing and is the most error-prone and time-consuming activity in energy analysis. Furthermore, this atomic activity is inadequate to fully represent the complexity of the process required to define building geometry for energy analysis, especially when dealing with complex design elements such as curtain walls. As a reference process for energy analysis, it fails to present in a form that is easily understandable by users.

We come back to this issue later in the paper where we propose an extension to this process map in order to accommodate curtain walls.

3.2 *Exchange requirement*

An Exchange requirement represents a link between process and data. With its target audience being the end user (in this case, the energy analyst), it provides a non-technical description of information that must be exchanged to support a particular business requirement at a particular stage of a project.

It consists of the overview, a set of information units and a result section. The overview section provides

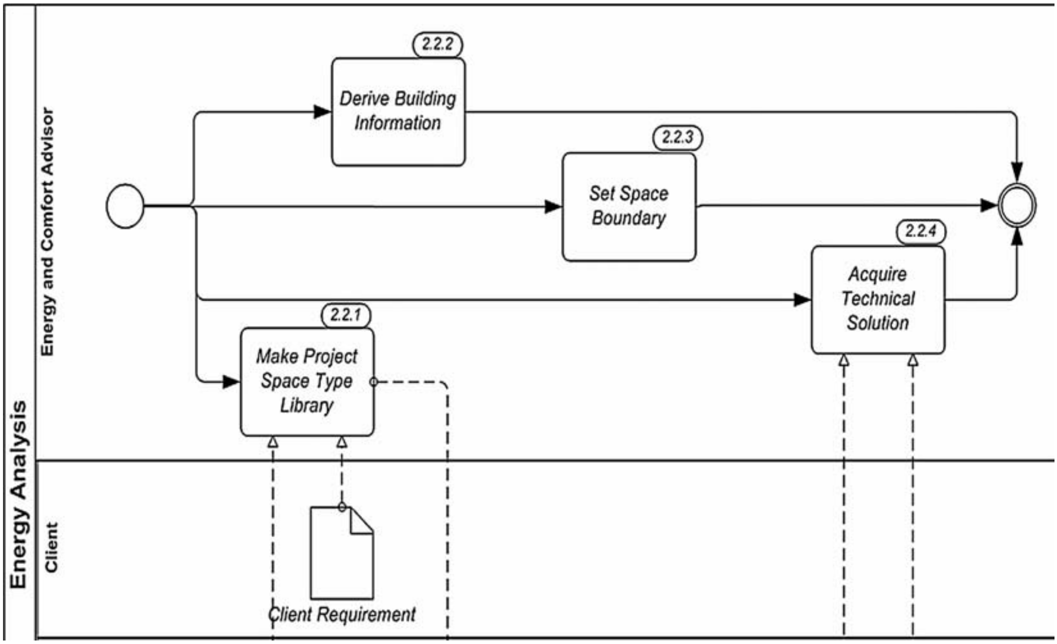

Figure 5. Expanded sub-process for "Obtain Building and Space Data" (http://idm.buildingsmart.com).

information to an executive user such as a project manager who needs to know the purpose of the exchange requirement but does not need to know the details of how it is achieved. Typically, the function of each information unit is to deal with one type of information or concept that goes to form the full exchange requirement.

Rules can be integrated into information units to meet specific requirements by controlling the way information is being exchanged. The rules established in information units can be developed into business rules for model validation.

3.2.1 *Current exchange requirement*

The exchange requirement for this process is called er_exchange_building_model [sketch]. It is shown in Figure 4 as an input to support the activity "Obtain Building and Space Data". An examination of that exchange requirement shows that it does not support the use of curtain wall element in IFC. Therefore, we will introduce a new exchange requirement specifically to handle the curtain wall case.

3.3 *Functional parts*

Functional parts are a technical specification of concepts. By referencing one or more functional parts in the information requirement section, one can establish an association to particular concepts or building elements within the IFC schema. This provides detail specifications for software developers regarding the capability of IFC to support the concept and hence, the process. As such, these become essential when validating the exchange process.

3.4 *Business rule*

A business rule provides a way to control the use of specific entities; it can be used to localize the expected result of using an exchange requirement. In the case of energy analysis for curtain walls, a business rule will be established to ensure that the curtain wall element contains the inverse attribute of "Is DecomposedBy" to facilitate the process of distinguishing vision and spandrel panels.

4 PROPOSED IDM EXTENSION

In order to represent both the current process in greater detail and to accommodate the special case where a curtain wall is involved, we have extended the process map for energy analysis during the design stage and developed a new exchange requirement specifically for the support of curtain wall elements. New concepts are introduced to facilitate the development of the exchange requirement.

For the base case representation, we imitate the way an energy analyst would model a curtain wall as if it were a more conventional wall with punched windows. However, the IFC schema for curtain wall elements is in fact very similar to a standard wall element, allowing it to be represented as an aggregated entity, but with no restriction on the nature of those decomposed elements. Therefore, IfcCurtainWall can be decomposed into ifcPlates and ifcMembers to represent the normal structure of curtain walls (where the plates can be of two types to represent vision and spandrel panels), or it can be simply treated like a standard wall and include ifcOpenings to accommodate window elements. Because the IFC definition is not explicit, our IDM extension needs to account for both possibilities, even though we are only looking at the base case.

4.1 *Process map extension*

The main actor in this process map is the energy analyst and the purpose is to formally represent the process of performing energy analysis. In this paper, we are concerned with the ability of IDM to formally capture the process of acquiring building geometry (the materiality of the building is handled in activity 2.3 in Figure 4). We have based our analysis of the data requirements for energy analysis on DOE 2.2 as it is an internationally recognized algorithm to support energy analysis and is the energy analysis engine used by eQUEST, one of the software tools approved by the Australian Building Codes Board. In addition, eQuest is instrumental in providing guidelines to the energy performance of glazing provision in the Building Code of Australia for non-residential building.

Related work in this area includes the development of the Geometry Simplification Tool (GST), an interface tool to take an IFC file and convert it into an input file for EnergyPlus (Bazjanac & Kiviniemi 2007), still undergoing beta testing. At the point of writing, we are still uncertain whether curtain wall elements have been supported in this development. It is envisaged that the extension reported in this current work will be fundamental in testing the functionality of GST.

We begin by extending the activity "Derive Building Information". We do this for two reasons. First, it serves as a vehicle to communicate the current process of acquiring building geometry to an energy analyst, enabling location specific best practices to be defined. For this reason, sub-processes have been named using terminology such as "define external building footprint" which is commonly used by energy analysts. This approach enables them to appreciate the fact that transition from paper to model based exchange does not change the workflow. Secondly, it serves as a reference platform for energy analysts, providing a better understanding of the function of exchange requirements. One of the key contributions of this extension is quality control as it allows the energy analyst to be certain about what information will be extracted from BIM and how that information contributes to the process of acquiring building geometry.

It is important to remember that the materiality of elements is defined elsewhere, in activity 2.3 (in Figure 4), and here we are only concerned with the geometry of the building elements.

In order to achieve these objectives, we extend the activity into the sub-processes shown in Figure 6. For the purpose of this breakdown of the process, it is assumed that a building is made up of one or more blocks, each with a number of storeys that have essentially the same configuration. This mirrors the eQUEST concept of shells that captures part of the building sharing a unique building footprint. The definition of activities shown in Figure 6 is then performed cyclically for each shell (indicated by to loop marker in Figure 6). In the current process, the analysis is performed one floor at a time within a shell, so the number of typical floors is defined in the activity "Set Number of Floors". The program will replicate the information in the subsequent activities for each storey.

The floor concept aggregates spaces on a floor-by-floor basis. Users are required to define footprint shape relative to the building using the space polygon concept before any spaces to preserve the hierarchy in the activity "Define Building Footprint". This is done by defining floor polygon with the assumption that conditioned space on that storey has uniform height.

Similarly, conditioned zones and the placement of spaces are described using polygons located relative to its parent floor under the activity "Define Zoning Pattern".

The concept of floor height needs to provide the flexibility for explicit modeling of a ceiling plenum. This is achieved in eQUEST by setting different values for space and floor height (where the difference, if any, is assumed to be the depth of the plenum). In our process model, this can be represented in the process map by placing a decision gateway prior to the activity "Define Space Height". This will verify if the object type attribute of space elements in the information model contains the value plenum. Where a space is explicitly defined as a plenum, the space height can be adjusted accordingly for the purpose of the calculation.

At this point of the process, sufficient information has been obtained about the external envelope to describe the geometry of external wall, roof and floor elements. The remaining steps in the process define the position of various openings and external shading devices.

By breaking the process down in to these atomic activities, we are able to deploy different exchange requirements to any of these atomic activities to

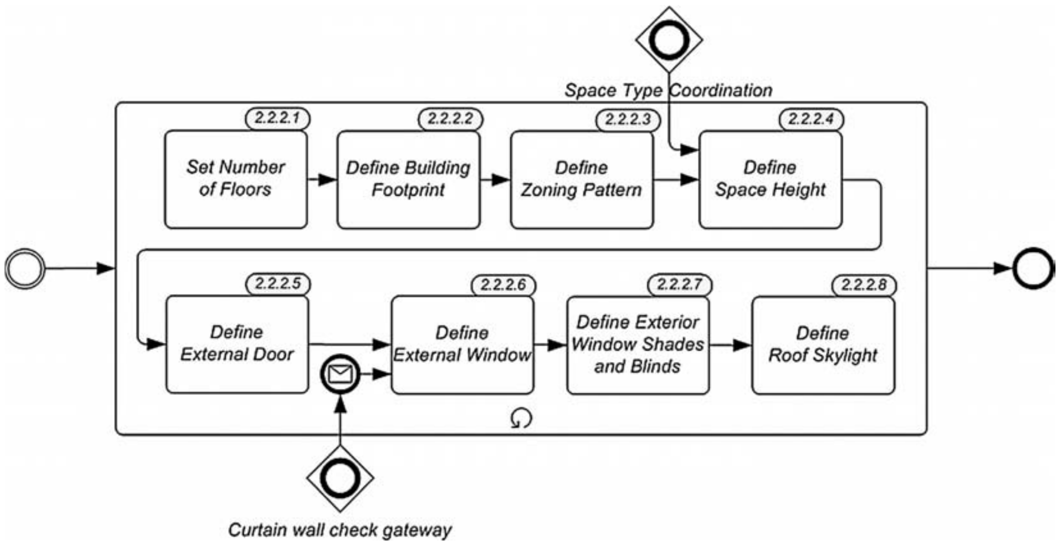

Figure 6. Extension of activity “Derive Building Information”.

accommodate context-specific requirements. It also allowed plenum and conditioned spaces to be differentiated.

As discussed in the previous section, there is no prescribed way to define a curtain wall in the IFC standard, so we need to insert a business rule into the process to check for such elements. The business rule localization approach will ensure that the appropriate exchange requirement is used to abstract accurate glazing area from the BIM irrespective of how the curtain wall is defined.

It is critical that the process of differentiating vision and spandrel panel is formally represented in IDM to effectively capture glazing requirement. Being a decision-making process that needs to happen before exterior windows are defined, this is represented by placing a coordination gateway before the activity “Define Exterior Window”. Three business rules will be applied to this gateway to assist in the decision process. First, we need to verify whether the building model contains a curtain wall element. Secondly, we need to know whether the curtain wall element has been decomposed into other elements. And finally, for the purpose of energy analysis, we need to ensure that the curtain wall is represented as a normal wall with windows located appropriately (irregardless of how it is actually modeled in the source BIM). This is further discussed in the next section.

4.2 *Exchange requirement extension*

We consider the exchange requirement *er_exchange_building_model [basic]* shown in Figure 5 adequate for defining window geometry of punched window design. However, it does not support the exchanging of curtain wall elements where these are decomposed in to panels and framing members. As a curtain wall is more complex than conventional window design, it is more difficult to obtain the dimension of vision panel than punched window. Therefore, we propose to have a new exchange requirement to handle the user requirement of exchanging curtain wall elements to support energy analysis. The relevant description for the requirement is documented in the information requirement section of the exchange requirement.

In this work, we are deriving the exchange requirement from an existing application (eQUEST) because we believe that it represents the typical approach taken by thermal analysts in current practice (in Australia). In cases where an application already exists to support the process, the suggested “reverse engineering” method is used to develop an exchange requirement (Wix 2007). The steps in developing an exchange requirement using this approach are discussed in the following sections.

4.2.1 *Define scenario*

There are two scenarios in the case where a curtain wall is explicitly defined in the source BIM: either it is represented as a wall with window openings; or it is decomposed into plates and framing members. In either case, the exchange requirement needs to reflect the input required to support energy analysis using eQUEST version 3.6 as a graphical front end with DOE 2.2 as the analysis engine.

Table 1. Information requirement for defining vision panel.

Type of Information	Information Needed	MAN	OPT	Actor Supplying	Functional Part
Building Elements					
Curtain wall	As energy analyst is concerned with accurate definition of its vision portion. Curtain wall for energy analysis can have two representation:	√		Building Design	fp_model_plate
	It can be represented using aggregated entity of IfcCurtainWall.				
	RULES:				
	The value assigned to IfcRelAggregates.RelatedObjects shall be IfcPlate and IfcMember.				
	The enumeration for vision and spandrel should be CURTAIN_PANEL and SHEET respectively.				
	Alternatively, curtain wall can be represented as a standard wall with windows in it. In this case, dimensional information and placement of vision panel, to be used in energy analysis software, will be derived from window entity from BIM				fp_model_window

4.2.2 *Recover data*

If the curtain wall has been decomposed into spandrel and vision panels, then the data recovery process must extract the required data from that representation. In this case, external wall height is set to the height of the storey. Vision panel are modeled as window, which is a child object of exterior wall (spandrel). Window height and its vertical placement in relation to its parent can be entered through window and sill height field respectively. Window width and horizontal offset in relation to its parent wall can be derived using the percentage window option and window height. The input parameters defined here will be the basis for the information requirement section of the new exchange requirement.

4.2.3 *Create exchange requirement*

Since no restriction has been placed on curtain wall elements in the IFC model schema, two scenarios will be defined here. First, we will focus on curtain walls represented by IfcCurtainWall with its associated inverse attribute to define its decomposition into panel and frame elements. Secondly, we will look at the scenario where curtain wall is being represented by an IfcCurtainWall with IfcOpenings (to accommodate window objects) associated with it.

The scenario described in 4.2.1 will form the overview section which informs end user of the purpose of this exchange requirement. The input parameters identified in 4.2.2 will define major information units of the new exchange requirement. This consists of textural description of the exchange requirement, allowing end-users to have a better understanding of its actual functionality.

Since all the geometric data for the external wall is derived from the footprint and space height, it is necessary to derive information from the curtain wall element to define dimensional information for the spandrel panels.

It is argued that while the input parameters remain the same, different IFC attributes are required for different representation to ensure accurate determination of glazing area. As shown in Table 1, different functional parts are referred by the information unit curtain wall. This provides information regarding the schema to software developer on entities required to implement this exchange requirement.

4.2.4 *Create functional parts*

The exchange requirement can be fulfilled with the use of functional parts. It is recommended that functional parts fp_model_plate and fp_model_window be used to establish size and position of vision panel. In cases of an extruded area solid representation for IfcSpace, minor modification to fp_model_space is required to include the depth attribute to support the definition of space height. This would provide enough information for eQUEST to determine dimensional information about the spandrel panel. It is recommended that the modification of functional part be achieved through a business rule which will be discussed in the next section.

4.2.5 *Define business rule*

The set of business rules that may need to be applied over and above the exchange requirement/functional parts should be defined. These may be used to determine attributes/properties to be

Table 2. Rule Table.

Rule ID	Name	Proposition	Allowed value
Rule-001	SpaceTypeMustBeDefined	Space type must be defined	IfcSpace.ObjectType="Plenum"
Rule-002	CWMustBePresent	Curtain wall is presented	EXIST IfcCurtainWall=.TRUE.
Rule-003	CWMustBeDecomposed	Curtain wall must have the inverse attribute "IsDecomposedBy"	Self\IsDecomposedBy=.TRUE.
Rule-004	DecomposedTypeMustBeWall	Curtain wall must be decomposed by window and wall	IfcRelAggrgate.RelatedObjects =IfcWindow or IfcWallStandardCase
Rule-005	ShapeRepresentaionIsExtrudedSolid	Space representation is Extruded Solid	IfcShapeRepresentation= IfcExtrudedAreaSolid
Rule-006	SpaceDepthIsDefined	Depth attribute of IfcExtrudedAreaSolid is presented	EXIST IfcExtrudedAreaSolid. Depth =.TRUE.

asserted or to control values that may be given to attributes/properties. As mentioned before, a business rule, br_exchange_curtain_wall has been developed to provide control on the behaviour of the exchange requirement. Rules, containing specific details about their purpose, are collected in tabular form as shown in Table 2. This is to ensure that consistent terminology is maintained between the BIM and energy analysis software. For instance, when rule-002 is applied to the coordination gateway, it will ensure that 2correct attribute has been extracted from BIM to support the activity "Define Exterior Window".

4.2.6 *Capture process*

This exchange requirement has the potential to provide the most comprehensive support to the activity "Define Exterior Window" by formally capturing the information required for accurate prediction of solar radiation transmitting into a space in existing applications. It will be placed before the activity "Define Exterior Window".

Indeed, the information section does provide adequate support for capturing user requirement. But I believe that the concept of exchange requirement model is important. The important thing is how to integrate functional parts and business rules in an exchange requirement model to realize the exchange requirement.

5 FUTURE WORK/DISCUSSION

The next step in the development of this work is to implement the IDM using an IFC model server environment to validate the exchange requirement and to test a range of IFC exports from different BIM applications against the business rules and the capacity to fulfill the information requirements for thermal analysis. Through this implementation process, invaluable insight will be gained to improve software development (both from BIM and energy analysis perspective) and giving end user confidence in exchanging information using model based approach. The interaction with façade engineer, including the definition of actual product performance will also be incorporated in the next stage. This will allow a comprehensive description of best practice in analyzing the energy impact of fenestration systems.

One of the controversial issues in defining best practice processes is the need for explicit definition of representation for curtain wall. In particular, inverse attributes have not been fully implemented to take advantage of IFC. This can be attributed to the fact that view-specific use cases for curtain wall representation have not been formally defined. Thorough understanding of downstream business processes is the key to developing use cases for software developers. We envisage that the combination of business rule and exchange requirement discussed in this paper will inform the development of curtain wall representation not only to support energy analysis, but to represent the nature of curtain walls so as to support a full range of analyses and uses.

In addition, we plan to compare this base case to a more precise description of curtain walls to see whether more advanced energy analysis engines, such as EnergyPlus, can measure thermal performance more accurately. It is anticipated that this will lead to a more robust exchange process.

6 CONCLUSION

In this paper, we have learned that ambiguity exists in the way curtain wall are represented and IDM has the potential to overcome the ambiguities using business rules and exchange requirements to explicitly define the appropriate representation. The development process for IDM also enables a flexible platform to visually communicate user requirements. Through the textural description of exchange requirement, it informs end-users of the information that has been abstracted from a Building Information Model. It is posited that this would be useful in capturing accurate glazing area. In particular, the exchange requirement approach provides an effective way of communicating information requirements.

In addition, the use of exchange requirements enable software providers to understand the scope of work needed to support the exchange requirement by looking at functional parts that are identified in the exchange requirement.

We envisage that this work will provide a vigorous foundation for software development, resulting in better user interfaces for software solutions and solid proof on code compliance.

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REEB: A European-led initiative for a strategic research roadmap to ICT enabled energy-efficiency in construction

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ABSTRACT: Increased energy demand and consumptions set down the challenge of our tomorrow energy and its optimised management, and have a detrimental effect on the environment due to carbon emissions and climatic changes. There is a growing and indeed crucial need to ensure energy efficiency in all industrial sectors in our future world, and especially in the built environment. In such a landscape, Information and Communications Technologies (ICT) can play a growing role in upholding energy efficiency and sustainability of buildings through better knowledge of, access to, and use of related energy information supported by new methods, processes and tools, as developed in more and more current RTD projects. As a response to the need for co-ordinating and rationalising current and future RTD in the area of ICT support to energy efficiency in constructions, the recently launched EC Co-ordinated Action REEB is an initiative that has been set to develop a European-wide agreed vision and roadmap providing pathways to accelerate the adoption, take-up, development, and research of emerging and new technologies that may radically transform building constructions and their associated services in terms of enhanced energy consumption.

1 CONTEXT AND RATIONALE

Energy efficiency (EE) is a key challenge for our world of tomorrow, leading to a twofold bet, both energetic and environmental, relating to climatic changes and carbon emissions, decrease and cost of oil resource, and an outburst of expenses related to energy. This fundamental EE goal spreads over all industrial sectors, including transport, aviation, manufacturing, etc. The Building Construction[1] sector, in this context, is at the forefront of challenges and expectations: for instance, in Europe, between 40% and 50% of the energy we generate goes into heating and powering buildings, accounting for around 30% of the carbon emissions, and it is recognised that ∼50% of savings to meet Kyoto objectives can be obtained by EE in Buildings & Construction. According to Eurostat, private household energy use contributes approx. 41% to Europe's energy needs while traffic contributes 31% and industry 28%. An individual family uses approx. 70% of its energy consumption around the house. A significant reduction of European energy consumption would be possible with the development and application of new products to be used in new and existing homes as well as in public buildings such as schools, hospitals, administrative centres, etc.

Therefore, the need is urgent to improve management of energy in Buildings over the whole lifecycle, i.e. from construction, through occupancy (between 50 to 100 years) and through demolition (and re-use). This reveals even more crucial in a context where trends are towards increased use of air-conditioning (due to climate change), raising standard of living, and increasing building stock, whatever the type of buildings considered (residential buildings, houses, office buildings, schools, etc.). For the sake of simplicity, we will refer in the rest of paper to "*Construction*" for Buildings, Built Environment and (smart) Facilities.

There are of course various areas of Technologies as well as Research and Development (R&D) delivering pieces of solutions to solve the overall EE puzzle. Typically, technologies like wind turbine, solar panels, fuel cells, heat pumps and exchangers, energy recovery & transformation, sensors, new materials (insulation, phase changing, radiant heat barrier, photovoltaic, electrochromatic, etc.) provide with means of (at least locally) improving energy use and control in Buildings. EE structural solutions, that focus on the building envelope and improve energy use as well, are another interesting area of potential development. However, besides taking into account the various

[1] considered here in a broad perception, which includes houses, residential buildings, office buildings, large infrastructures (harbours, airports, etc.), facilities like tunnels, and up to urban management. Moreover, Buildings refer to all types of buildings, whether they are new, or being used or to be renovated, either they are residential, tertiary, or industrial.

equipments and the infrastructure of the building itself, also the way all these equipments and building components are networked and interoperable, and the use itself of buildings (private or professional space) have to be considered in the global equation. This is drastically a new approach: considering energy, it will allow to provide an optimal management of all building energy flows. This is where ICT is recognised as playing a fundamental role in the future, for the development of "Building Automation" and especially the improved management of energy, leading to the so-called "energy-efficient smart buildings" of tomorrow.

The idea of using ICT to support "Building Automation" (should it be for improving energy efficiency or for other functional targets) is not *per se* a new one, but the approach to be considered and developed today, supported by a truly new ICT environment largely impacted by the Internet or Ambient Intelligence, is radically to be a more innovative, comprehensive and systemic one. "Building automation", 15 years ago, did not have the impact expected at that time, especially as it was essentially a matter of "system automation" targeting few classes of equipments within the Building, not standardised, not interoperable, and with raw local strategies for enhancing the functionality. Yet, today, and out of any "mediatisation" scope, "intelligent" products are more and more integrating the built environment, at various pace according to applications (very fast for multimedia, a bit slower for electric household appliances and health, and very slow for energy management), but the breakthrough can do nothing else than accelerate taking into account the increasing request of society in term of information, means of communication, safety, but also and even more energy optimization: the "energy-efficient smart building" is expected to be a major asset in sustainable development by providing an optimal management of building energy flows.

As a consequence, problems must henceforth be considered according to a global and integrated approach, involving all the players in the building industry (manufacturers, material suppliers, construction firms,...), designers, installers, developers of energetic systems, primary energy providers and utilities companies, building owners, building operators, maintenance and service providers, Financial/ investment institutions, National, regional, and local policy-makers and regulators, as well as software developers and vendors in terms of ICT support – and considering that ICT impacts both the design process and living in the building. Moreover, ambitious objectives[2] have been set in terms of Energy efficiency, that are leading to complex technical and organisational issues to be solved, with ICT being key to support the development of adequate solutions (products & services):

- More effective involvement and collaboration of organisations belonging to ICT community and Energy/Environment communities into innovation activities: faster and wider collaboration will increase creativity potential and innovation capacity as well as business opportunities in the enlarged EU to all stakeholders;
- Increased EU, government and industry investment in research related to ICT-based informed decision-making for delivery and use of sustainable and energy-efficient facilities;
- Acceleration of innovation and emergence of new businesses, in facilitating access to EU developers and practitioners' communities, appropriate partnership, and opportunities of participation to research projects, including the SMEs;
- Acceleration of deployment and implementation of research results, and potential wide-spread adoption, thanks to a comprehensive approach for dissemination and marketing of R&D outcomes. This may include emergence of new ICT-based concepts, technologies and practices for energy self sufficient buildings or Energy positive buildings connected to energy distribution networks.

In the context of the EC FP7: Theme 3 "Information and Communication Technologies" – *ICT for Environmental Management & Energy Efficiency* – the "European strategic research Roadmap to ICT enabled Energy-Efficiency in Buildings and constructions" (REEB) project is a co-ordinated action that has been launched in May 2008 with the main ambition of *co-ordinating & rationalising current and future RTD in the area of ICT support to EE in the built environment of tomorrow*, and with the intention of:

- Stimulating government and industry investment in research related to delivery and use of sustainable and energy-efficient facilities (through ICT-based informed decision-making);
- providing instruments to better organise research focused on ICT-based informed decision-making for delivery and use of energy-efficient facilities;
- sustaining the future deployment and implementation of research results throughout government and industry (i.e. achieve wide-spread adoption).

[2] E.g. in France, for new houses/buildings, all to be Low Energy Buildings or Energy Positive Buildings (EPB) by 2020, with 1/3 with max 50 kWh/m^2/an and 10% being EPB; for non-residential buildings, 50% with less than 50 kWh/m^2/year and 20% being EPB. For existing houses/buildings, decrease by 2020 the average consumption down to 150 kWh/m^2/year (today: 240 kWh/m^2), and for non-residential buildings, by 2020, down to 80 kWh/m^2/year (today: 220 kWh/m^2/year).

2 MAIN PROBLEMS AND CHALLENGES JUSTIFYING THE REEB CO-ORDINATED ACTION

REEB intends to identify, synthesise, classify and get to a common agreement of the main problems and challenges (so as to further prescribe R&D new ICT-based solutions) related to the future delivery and use of sustainable and energy-efficient facilities and buildings, through ICT-based informed decision-making (both human and automated). Most of these problems connect to the following families:

- Inadequate ICT-based informed decision-making (both human and automated) in the current delivery and use of sustainable and energy-efficient facilities, with issues related to availability of Data/Information (D/I), appropriateness of D/I source and reliability of D/I, D/I collection methods and integration, D/I transfer, transformation, use and delivery to stakeholders, etc.;
- Current delivery and use of facilities does not necessarily lead to sustainable and energy-efficient buildings, due to:
  - Lack of (common) agreement of what sustainable and EE buildings are;
  - Too many standards regulating buildings that affect delivery and use, with some being in conflict with others towards achieving sustainability and energy-efficiency;
  - Lack of (common) agreement on holistic and systems-based view of buildings, and of industry agreement on measurement and control;
  - Too many options to choose from regarding environmental systems and their configurations.
- Need for post-occupancy feedback to user to enable behaviour modification towards sustainability and energy efficiency, including definition of user requirements and preferences, dynamic and personalized environmental controls, visualization of data associated with energy use, etc.;
- Need for management of energy types and distribution in buildings and urban areas, including integration of multiple sources of energy, and balancing and optimization of energy sources and uses;
- Inadequate D/I on, and methods for establishing, sustainability, energy efficiency, and other attributes of materials and products used in facilities, including assessment, smart labelling, logistics, etc.

The current Gaps and Foreseen Research/ Technological Challenges related to ICT for energy-efficiency in the Built environment include:

- Systems-thinking, multi-stakeholder, and multi-disciplinary design and construction of sustainable and energy-efficient facilities;
- Pre-designed/engineered, replicable, and flexible environmental systems solutions, e.g. optimization, adaptation, and scaling to specific context applications, and configuration tools to do so;
- Cost-effective deployment of specific ubiquitous sensing networks – along with the seamless adaptation of moving environment context, e.g. adding or removing resources;
- Incorporation of the human dimension (as end-users) in ICT, especially through solutions that are "accepted" by the user, e.g. with systems naturally interacting with the user (voice, avatar, ...), with systems having the capacity to learn and adapt themselves to the way of living or working, with dynamic adaptability to the user specificity (handicap, health, age, ...), etc. – overall an issue of human activity related to energy efficiency, and of the design of the interface accordingly;
- Understanding and development of quantitative tools that match reality;
- Scaled and selective mining, as well as visualisation, of D/I within enormously large databases, along with integration of disparate databases;
- Development of mature, fully functional, and robust domain and cross-domain software tools and ICT-based services for industry;
- Development of formal models for performance metrics for sustainability and energy-efficiency in buildings and urban areas.

3 THE REEB OBJECTIVES

The REEB approach is to bring experts from the Construction, ICT and energy knowledge domains together so as to elaborate a common view of the current challenges, state-of-the-art, vision of a future state, and roadmapping of future RTD in ICT support to Energy-efficient Construction. This is made

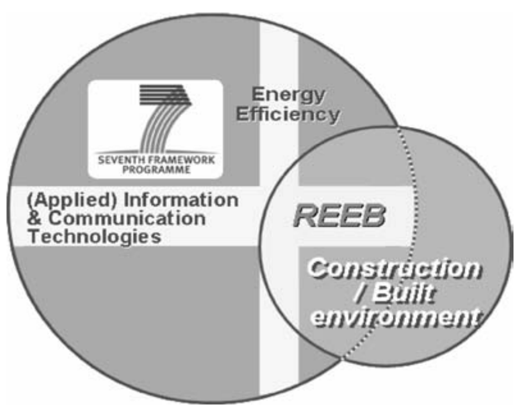

Figure 1. REEB at the crossing of three areas.

possible especially thanks to a Consortium formed by partners being at the crossing of these knowledge domains: the consortium involves 8 partners (5 RTD, 3 industry) with complementary expertise, profiles, required skills and roles drawn from 6 European countries (France, Finland, Spain, Ireland, UK, Germany).

The REEB objectives are described in the table below:

Project Goals	Project Activities/outcomes
Set up European community	Establishment of a European-led community dedicated to the innovative use of ICT supporting Sustainability and Energy Efficiency in Construction, bringing together the (Construction) ICT community and key actors of the (Construction) Environment and Energy business sectors. This will include: • Liaison with Central & Eastern Europe stakeholders – through the ECTP FA7 and other ETPs related to EE buildings (12 being already identified, including Artemis, eMobility, Manufuture, NESSI, SmartGRids, etc.); • International cooperation, through common Workshops with: CIB, FIATECH, as well as the E2B Joint technology initiative.
Set up National Communities	Mirroring and relays in each country (in a first stage in France, Finland, Germany, Spain and Ireland) of the European Community. This will include: • consideration for SMEs – mainly through national associations whose representatives are to be invited to national workshops; • Policy makers – through invitations to workshops of dedicated (personal) presentations and discussions. Especially, funding organisations involved in the former ERABUILD project and its follow-up ERACOBUILD.
Identify Best Practices	Identification of a comprehensive set of best practices for use of ICT applications and tools for energy efficiency in Europe and world-wide – and selection of a small set of most representative practices as detailed examples. Objective also includes considerations for: • Standardisation – with the identification of set of initiatives and R&D works targeting aspects of home and building automation, and integration of electronic devices and systems in facilities, and in relation to ICT (e.g. CENELEC TC 205 (Home and Building Electronic Systems), KONNEX (KNX technology & standard), ECHELON. . .). • Regulations, both in terms of European ones (e.g. EPBD[3]) and national ones (e.g. RT2005, RT2010 in France); →Best practices will be first and fundamentally collected in countries of participating partners, but also all over Europe thanks to National and European communities.
Inventory of RTD results	The activities will achieve cross-fertilisation and potential harmonisation among national, European (especially EC-funded and international recently finished and on-goings projects), and will kick-start the R&D and industrial dissemination. Co-ordination and support for IST projects dissemination will be provided, and the REEB objectives will be primarily to create opportunities for the participating projects involved, to exchange experience and disseminate results, and will aim to explore and exploit synergies between projects. It must be clearly stated that it is the intention of REEB to also reach out to and involve other projects which might be started in the future, e.g. through future IST calls, during the duration of REEB. It is anticipated to set up a mechanism by which key indicators can be defined, and collected as part of a systematic, ongoing impact analysis of RTD projects for future technology transfer of or future R&D in ICT-based EE.
Development of a shared vision, SRA and implementation recommendations	This will be developed with the focus on the ICT domain to support energy efficiency in the Built environment and its connection to energy distribution, to build-up consensus on an innovative vision and roadmap, with feedback from the REEB stakeholders, for the development of the SRA[4] and IAP[5] that will: ◦ define vision and priorities for future research (including in the FP7), through establishing a research agenda for the upcoming 10 years;

[3] European Performance Building Diagnosis

[4] Strategic Research Agenda

[5] Implementation Action Plan

	∘ identify programme collaboration and co-operation policies (including standardisation, dissemination and demonstration policies) between European and national funding bodies and initiatives, towards the defined strategic goals and priorities; ∘ establish a set of recommendations for implementation (i.e. Why, What, When, Who, Where and How).
Dissemination – including education & training	Elaboration of a detailed plan for coordination of information exchange and dissemination between all energy-related ICT projects, initiatives and stakeholders. Development of e-learning lecture courses for students as well as for industrial people – offered in the course of a virtual European Master programme in Construction Informatics.

4 THE REEB WORKPLAN

The REEB project, over a 2 years (24-month) plan, aims at the provision of support actions by various means, with many tasks purposely spanning the whole project lifetime, each task feeding results to each other and creating synergy in strong inter-relationships. The principal meaning, purpose and use of these inter-relationships are presented on work package level in the figure below.

The work packages are structured in a way that allows to:

- rapidly put in place and make enlarged the REEB community while achieving awareness and wide involvement: WP1,
- make an inventory of the current best practices at national, European and international levels, including standardisation trends: WP2,
- make an inventory of the current RTD results, both in terms of projects that have recently achieved their works or are still on-going, with a focus on trying to harmonise outcomes from European RTD projects, but also national projects and key projects outside Europe: WP3,
- define a strategy to support the vision, and its future implementation through a strategic research roadmap and recommendations for Implementation Actions: WP4,

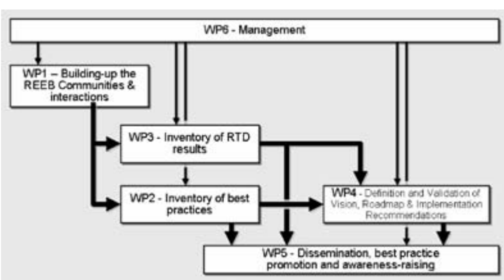

Figure 2. Global strategy and workplan.

- develop and put in place all the required dissemination to achieve optimised dissemination, promotion of best practice and RTD results: WP5; and
- ensure the overall co-ordination and management of the project, and fine-tuned cooperation with the EC: WP6.

5 IMPACT AND PERSPECTIVES

The European Union has acknowledged that applications in support of the environment, risk management and sustainable development are growing areas where European citizens can reap real benefit from ICT products and services, to improve seamless access and interactivity of services of broad public interest. This is mostly true in the field of energy efficiency, where improvement through innovative ICT can be tackled in many ways, e.g.:

- ICT methods and tools supporting optimal design and commissioning of products and services with respect to energy consumption and the related environmental impact - with coverage of the entire lifecycle of products and services from requirements analysis to their final elimination.

- Integrated ICT-based systems enabling an eco-efficient production, conservation and distribution of energy – guaranteeing safe and reliable provision of energy and possibly integrating various energy sources and transformation processes (e.g. cogeneration).

– New ICT-based control and monitoring systems applicable to industrial processes, office buildings, living environment (e.g. at home) in order to optimise energy consumption and to reduce environmental impact.
– Design, simulation and strategy adaptation of energy use profiles, especially in terms of in-house/in-building consumption management, with a focus on energy-neutral new or renovated home and working environments, supported by innovative business models and platforms for energy efficiency service provision.

One of the key objectives is to establish a better understanding, a closer dialogue and active collaboration between end-users/practitioners and solution/technology-suppliers through regular discussion/debate events either in face-to-face or on-line meetings. Types and relationships between all those stakeholders (for smart facilities, and indeed covering energy-neutral or energy-positive facilities) are exhibited in the figure below.

It is expected that the global result of REEB will be an improved participation, more effective involvement and cross-fertilisation of industrial organisations, RTD institutes/academia and companies – including SMEs – in terms of defining future RTD and priorities for ICT-based energy efficiency in the Built environment throughout Europe, further leading to influence future IST research programmes, provide opportunities of cooperation for the development of future RTD projects with ambitious objectives while at the same time enhanced structuring of the cluster of projects in this field, so as to achieve a notable desired impact. The figure below provides with a potential vision of the expected impact at various levels.

Especially, a fundamental objective of REEB is to encourage and facilitate the participation of industrial organisations in future European Union IST research activities through their involvement in the REEB

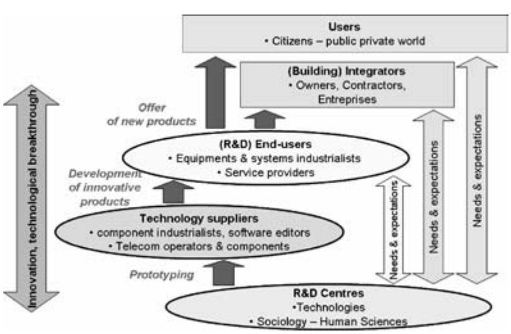

Figure 3. Global Value Chain for products, systems & services in a global functional approach of smart facilities.

community, as well as offering possibilities of transferring technologies to developing regions and countries, contributing to solve the great global problem on sustainable energy uses. Such an ambition can only be achieved:

– by the stimulating and intensifying synergies between (IST-funded and NMP-funded, and related to energy issues in Construction) projects and potential stakeholders in the REEB communities in Europe. Moreover, REEB intends to support an enhanced co-ordination of European research activities, in particular by bringing in line various national/EU RTD programmes and top level academic and commercial European RTD in the area of ICT-based Energy efficiency in the Built environment;
– by establishing permanent relationships between technological partners across Europe making use of REEB consortium involvement in major initiatives such as Energy Efficiency in Buildings (E2B) and ARTEMIS Joint Technology Initiatives;
– by providing widespread support from a holistic approach through the establishment of links between different stakeholders including ICT-oriented technology platforms such as ARTEMIS and construction related forums such as ECTP;
– by facilitating an integrated multi-disciplinary approach. One of the most important political and organisational challenges of the next ten years is the integration of research and industrial communities into activities targeting the coming research challenges within future IST research programmes on the base of a shared vision. It is the strong intention of REEB to focus among others on a multidisciplinary and multi-cultural approach, bringing national and European communities and stakeholders together in developing a strategy and research agenda for high-impact innovation in ICT-based EE in the Built environment;
– by speeding up the market uptake, and by increasing and improving trans-European RTD, leveraging on key European players in the area of ICT and Energy. This guarantees the critical mass for the REEB results. In turn, it is expected that this will lead to World leadership in the development of "next generation high efficiency" products and solutions for improved energy monitoring and efficiency in Buildings, and in areas such as energy use and consumer convenience.

6 CONCLUSION

The REEB project addresses the strategic objectives of IST and the ERA by:

– targeting a key industrial sector in Europe: Construction represents between 40% and 50%

(depending on the countries) of energetic consumption all over Europe, and around 30% of CO2 emission. As far as REEB is concerned, the project is expected to help strengthening Europe's progress in these issues by building and structuring a critical mass focussed on ICT supporting energy efficiency in Construction sector;

– trying to as comprehensively as possible identify R&D activities needed for systemic and disruptive approaches required to bring about changes, including increasing faster innovation cycles and focus on higher parts of the value chain of ICT-based energy management.

The need for a European approach is indeed obvious, as multi-disciplinary activities are more and more often performed at a European level, involving actors from different countries with a strong need for co-operation and business exchange, despite technological, organisational and cultural differences. Therefore, there is a clear need to achieving a consensus on a common vision, including practical measures for agreement on potential applications and standards to be adopted by the industry at a European or even worldwide level, as a fundamental issue to improve the use of ICT for energy efficiency in the Construction industry.

The essential challenge and expected impact for the REEB project is to guide and back up the development of innovative businesses and application concepts and tools improving existing solutions for EE in the Built environment or leading to new ones, and based on advanced innovative ICT instruments to be introduced in a fully integrated and systemic approach. The final aim is to improve the efficiency of the construction sector and its output products and services, as far as energy is concerned, leading to better EE construction products and services.

ACKNOWLEDGEMENT

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IFC-based calculation of the Flemish energy performance standard

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ABSTRACT: This paper illustrates our findings concerning space based design methodologies and interoperability issues for today's Building Information Modeling (BIM) environments. A method is elaborated which enables building designers to perform an automated energy use analysis, based on an Industry Foundation Classes (IFC) model derived from a commercial BIM environment, in this case Autodesk Revit 9.1. A prototype application was built, which evaluates the building model as well as vendor-neutral exchange mechanisms, in accordance with the Flemish Energy Performance Regulation (EPR) standard. Several issues regarding the need for space-based building models are identified and algorithms are developed to overcome possible shortcomings.

1 INTRODUCTION

Today's building design practice finds itself subject to increasing expectations in several knowledge domains, striving towards building designs with better performance in a variety of fields. These challenges ask for a detailed evaluation of the building model in an early stage of the design process. At present, however, a building design is evaluated by experts, using specialized simulation tools, *at the end* of the design process, i.e. when important design decisions have already been made, without any quantified feedback (Suter and Mahdavi, 2004). Therefore, the design process would be greatly enhanced by the availability of uncomplicated evaluation methods, incorporated in, or at least closely related to, the designer's modeling environment. This requires a rich modeling environment, capable of communicating design data with external evaluation tools. Building Information Modeling (BIM) applications, in conjunction with efficient vendor-neutral interoperability methods, such as the Industry Foundation Classes (IFC) initiative (http://www.iai-tech.org/ May2008), are promising technologies to fulfill these requirements.

This paper focuses on the feasibility of this approach by devising a method to automatically evaluate a building design, modeled in Autodesk Revit 9.1, in accordance with the Flemish Energy Performance Regulation (EPR) standard (http://www2.vlaanderen.be/economie/energiesparen/epb/doc/bijlage1epb. pdf May2008). The most important challenge arising from the EPR standard is the need for a space-based model, which makes it an interesting test case, since most of today's modeling practice is not oriented that way.

Fazio et al. (2007) investigated an IFC based framework for delivering building envelope data to a set of simulation engines, showing that it is feasible to automatically derive the required geometrical and material layer information from a BIM application. However, the procedure focuses on the building envelope and less on three-dimensional, space-related issues. In contrast, the research of Lam et. al. (2006) does take the spaces defined by their enclosing constructions into account, and uses them as a start point for the thermal simulation. However, they make rather far going simplifying assumptions concerning the bounding construction geometry. It is precisely this aspect which is addressed in the current contribution. We target the faithful and complete generation of both the internal and external geometry of space-based models as well as their material properties, so to enable accurate calculation of the building energy performance. To realize such a system, various issues have to be faced, notably (i) the ability of contemporary BIM environments to capture and, most importantly, to export the required information, and (ii) the ability to deploy vendor-neutral formats to convey the information to the processing software. These issues are addressed, a prototype of such a system was actually built and is briefly presented.

The paper is structured as follows. The next section briefly introduces the Flemish standard against which the software has to operate. Then, in section 3, the well-known IFC format is evaluated with respect to the ease with which the information can be represented. In section 4, some of the solutions are presented that have made the construction of a prototype system possible. Conclusions are formulated in section 5.

2 ARCHITECTURAL DATA REQUIREMENTS FOR THE FLEMISH ENERGY PERFORMANCE REGULATION

As imposed by the *European Directive 2002/91/EC of 16 December 2002 on the energy performance of buildings* (Directive 2002/91/EC, 2002), the Flemish Authority has elaborated a standard with which newly erected and renovated buildings have to comply: the Energy Performance Regulation (EPR). The standard describes a steady state calculation of a building's '*characteristic annual primary energy consumption*', implying that some simplifying assumptions have been made, for example the use of fixed exterior and interior temperatures, default occupancy and internal heat gains. By doing so the EPR method does not aspire to assess the *real* energy consumption but delivers a workable basis for a comparison between buildings. In the following, aspects of the standard which exclusively focus on residential buildings are elaborated, the so-called EPW method.

The EPW method consists of calculating the following aspects of a building's energy demand: spatial heating and cooling, domestic hot water supply and the use of auxiliary equipment. Possible gains by solar panels or cogeneration devices are subtracted from the previously calculated energy demands. All contributions are calculated per month and, if applicable, per *energy zone*, a spatial subdivision which groups the spaces sharing a common heating and ventilation system. The previous terms are multiplied by a fuel factor and ultimately combined to provide the *characteristic annual primary energy consumption*, in short the building energy consumption.

In Table 1 the EPW method is summarized from an architectural point of view, describing those contributions which are explicitly related to architectural aspects of a building design.

3 MAPPING THE IFC-SCHEME

The Industry Foundation Classes (IFC) standard is a generic hierarchical object model to abstract building components and processes, it was defined to provide a universal basis for process improvement and information sharing in the construction and facilities management industries (http://www.iai-international.org/About/Mission.html May2008).

It is clear that the energy zone object plays a prominent role, since it groups all data required. Therefore, the IFC2x3 model scheme is evaluated in view of the following operations: (1) generating the individual energy zones, (2) collecting bounding constructions, (3) extracting corresponding geometry and material layer properties and, if applicable, (4) processing opening elements, related to their energy zone by the bounding constructions in which they occur. Some of the required data is explicitly embedded in the IFC2x3 model scheme, e.g., material layer thickness d, while other data, such as the opening element glazing fraction $F_{w,j}$ or solar factor g_j, are possibly provided through the *IfcPropertySet* objects. An essential part of the required data however, can only be extracted after (sometimes extensive) processing.

3.1 *Internal boundary of energy zones*

Combining the functional requirements for an energy zone with the IFC2x3 model scheme delivers the *IfcSpace* entity as best match for the energy zone

Table 1. Architectural data requirements for the EPW method.

Energy zone attributes	Transmission loss $Q_{T,zone,m}$ *MJ*	Ventilation loss $Q_{V,zone,m}$ *MJ*	Internal gain $Q_{I,zone,m}$ *MJ*	Solar gain $Q_{S,zone,m}$ *MJ*
External volume $V_{zone}(m^3)$		X	X	
Bounding construction external area $A_{T,zone}(m^2)$	X	X		
Bounding construction material layer thickness $d(m)$	X			
Bounding construction material layer thermal conductivity λ *(W/mK)*	X			
Opening element area $A_{w,j}(m^2)$	X	X		X
Opening element Slope θ_w *(°)*				X
Opening element orientation Φ_w. *(°)*				X
Opening element glazing fraction $F_{w,j}(-)$	X			X
Opening element glazing solar factor $g_j(-)$	X			X

functionality. According to the definition from IAI an *IfcSpace* '... represents an area or volume bounded actually or theoretically. Spaces are areas or volumes that provide for certain functions within a building.', note that this concerns internal dimensions. Additionally, the different bounding constructions for a given *IfcSpace* are provided by the set of *IfcRelSpace Boundary* entities, which each deliver a bounding construction by an *IfcBuildingElement* instance. Apart from the *IfcBuildingElement*, the *IfcRelSpaceBoundary* entity provides two very useful objects: *IfcConnectionGeometry* and *IfcInternalOrExternalEnum*. The former establishes the geometrical relationship between an *IfcSpace* and the related bounding construction, the latter states whether that construction neighbors the exterior or interior.

It should be mentioned here that, although the *IfcBuildingElement* and *IfcConnectiongeometry* attributes are optional for the *IfcRelSpaceBoundary* entity in the IFC2x3 model scheme, they are considered essential in this project, since by these attributes the connection between a bounding construction and a given IfcSpace is geometrically described. The connection geometry would be much harder, if not virtually impossible, to determine without the *IfcRelSpaceBoundary* entity, taking the separate geometrical representations of *IfcSpaces* and *IfcBuilding Elements* entities as a starting point.

Several possibilities are provided by IFC2x3 model scheme to define the connection geometry and different definitions are encountered when observing

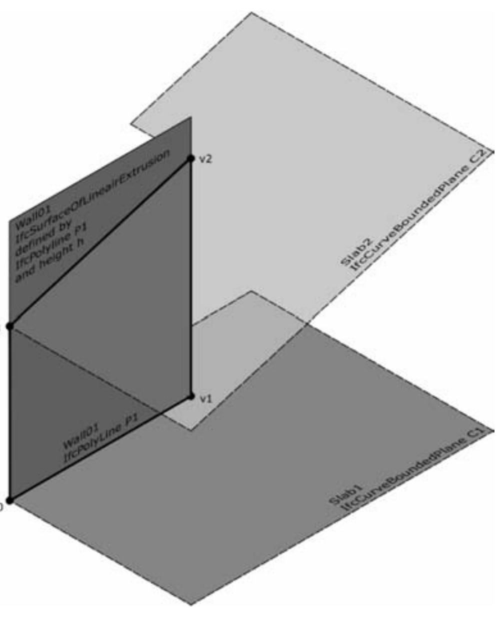

Figure 1. Connection geometry for wall01.

IFC models generated in practice. The connection geometry for slabs, for example, is often defined as an *IfcCurveBoundedPlane* instance,which provides a closed and planar curve, as a boundary facet. However, in compliance with the model scheme, the wall connection geometry might be defined by means of an *IfcSurfaceOfLineairExtrusion* instance. In that case, the generation of the curve defining a wall connection geometry is far more complicated. Merely a prismatic surface is provided, determined by a two dimensional profile, an extrusion direction and height. Surely, the profile to be extruded matches the line segment where the wall connects to the flooring, but problems arise when trying to define the line segment connecting the wall to the space ceiling. Note that the extrusion height is derived from the *IfcSpace* individual representation, which is in fact the space bounding box and therefore does not necessarily coincide with the exact shape. To overcome this problem, an algorithm has been constructed by which the wall connection geometry is developed more precisely. The development consists of calculating the vertices v_i which constitute a curve describing the wall-space connection. Looping through the vertices of the IfcCurveBoundedPlane C1 and C2, as provided by both slabs, and storing those which fit the *IfcSurfaceOfLineairExtrusion* for a specific wall, provides for a set of vertices. Each vertex is a member of both constructions, and thereby describing a bounding curve in the *IfcSurfaceOfLineairExtrusion*, which is determined by the two dimensional profile P_1 and height h. Finally, this set is post processed to ensure a correct order, resulting in a closed and planar curve, representing the wall connection geometry for a given space (Fig. 1).

With the *IfcConnectionGeometry* entity for each bounding element provided, the *IfcSpace's* internal geometry can be processed, resulting in a set of planar curves each related to an *IfcBuildingElement* instance or a specific part of it (Fig. 2). The internal geometry describes the *IfcSpace* as seen from the inside and its representation is assumed to define a closed shell.

3.2 *External boundaries of energy zones*

The internal geometry, which is in fact a closed set of curves, does not yet provide the data needed, i.e., the *IfcSpace* external volume V_{zone} or its bounding constructions external area $A_{T,zone}$. As illustrated in Fig. 1, gaps appear between neighboring spaces and the building's outside geometry is completely absent, due to the lack of geometry for all bounding constructions like walls, floors and roofs. We now describe an algorithm which inflates the *IfcSpace* internal geometry, to match its outer boundaries, by generating the boundary elements' volume. In a preprocessing stage, each curve is triangulated and its surface normal justified (Fig. 2).

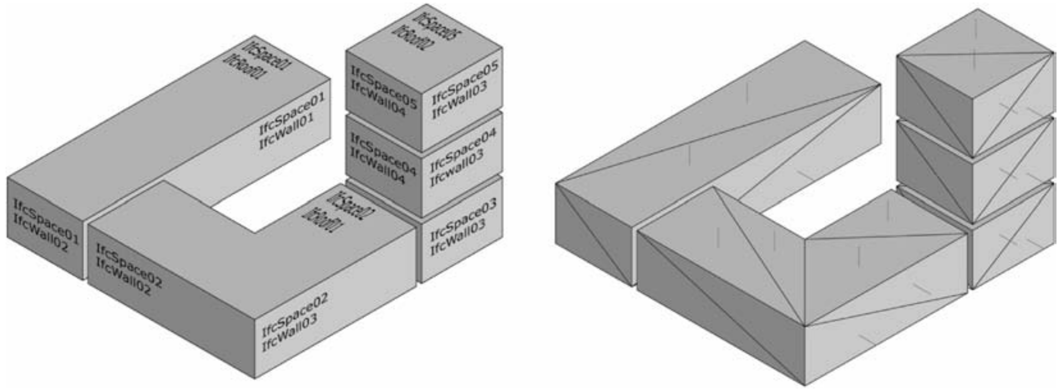

Figure 2. Left pane: Internal geometry for IfcSpaces, right pane: triangulation of curve set, addition of surface normal.

All construction components, e.g., walls, slabs, roofs, stairs, columns, Beams . . . are subtypes of the *IfcBuildingElement* entity, which provides the geometrical representations and material usage. The *IfcMaterialLayer* instance has an attribute *Layer Thickness* d_i and *IfcMaterial*. Combining the values for d_i results in the *IfcBuildingElement's* total thickness d_T. The *IfcMaterial* instance provides the material name and, possibly, a link to an external reference comprising physical material properties or specifications.

A procedure has been developed to generate the *IfcBuildingElement* geometry, derived from the curve sets described in section 3.1 and its total thickness d_T,which would then be space-related in contrast to its individual representation as described by the *IfcProductDefinitionShape* attribute.

Generation of the *IfcBuildingElement* space-related geometry, needed for the calculation of its volume calculation, consists of defining the outer curve, parallel to the inner space bounding curve, and all curves connecting the inner and outer curves. This is a vertex-based operation. For each vertex v_0 of an *IfcBuildingElement's* inner curve C, at least one new vertex v_0' is generated. The number of inner curves C_i containing v_0, the surface normals n_i and corresponding offset distances $d_{T,i}$ are the parameters required for the calculation. In most cases vertex v_0' is derived as the intersection point between three planes, defined by the surface normal and offset distance corresponding with its curve set C_i, however, different algorithms are used depending on the constellation of the inner curves of which v_0 is a common vertex (Fig. 3). Performing the procedure for a *IfcBuildingElement's* inner curve delivers a closed shell, enabling the calculation of its volume.

3.3 *Introducing the opening elements*

In Table 1 several requirements in relation to opening elements are listed: area $A_{w,j}$, slope θ_w , orientation Φ_w, glazing fraction F_w, j and solar factor g_j. In contrast with the first three requirements, which relate to the geometrical aspects of a void made in a construction element, the latter two relate to the objects which fill the void.

In general the geometrical representation for the voiding *IfcOpeningElement* consists of an extruded solid object, defined by a two dimensional profile and extruded orthogonally to the wall's face. Sometimes a boundary-representation object is used as the opening's geometrical representation. In that case the boundary-representation bounding box is calculated and analogously treated as the previous solid object.

The key to establishing the relationship between the *IfcOpeningElement* geometry and the *IfcSpace* inner geometry is the two dimensional profile, used by the extruded solid object, by which the opening is described. By projecting this profile, parallel to the extrusion axis onto the host construction's inner curve, the opening's geometry is embedded within the bounding construction's new representation. A new curve is generated, representing the part of the construction where the opening is located and the opening's area $A_{w,j}$, slope θ_w and orientation Φ_w are calculated.

The solar factor g_j and the glazing fraction $F_{w,j}$ are retrievable via the *IfcWindow* or *IfcDoor* instance, accessed through the *IfcRelFillsElement* instances.

4 PROJECT CASE, FEEDING THE EPW APPLICATION FROM REVIT 9.1

In this project, Autodesk® Revit 9.1 was used to model an office building design and perform its export to the IFC2x3 data format. The building consists of six spaces, arranged around a patio in a split-level layout. Spaces are defined by means of the Revit room object, construction components are provided with corresponding material layers and opening elements are

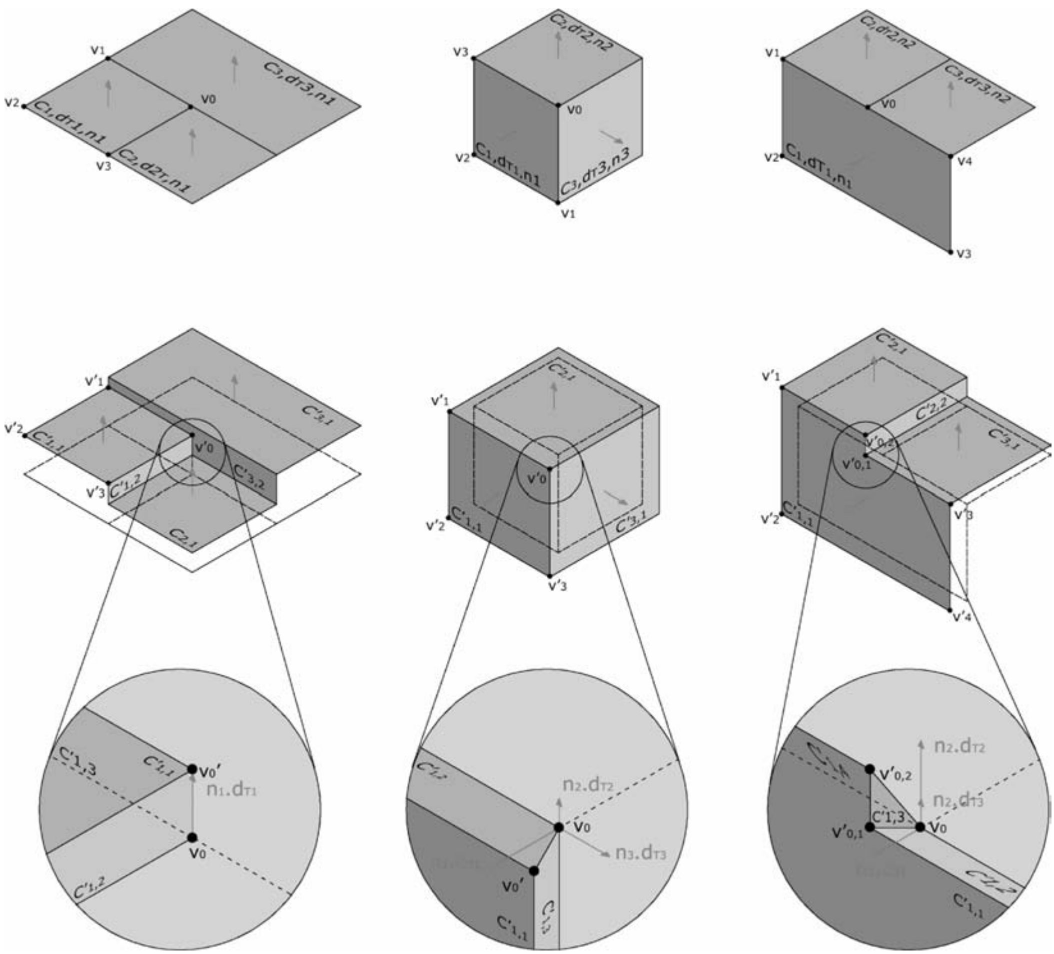

Figure 3. Offset cases: one, three and two surface normals for a given vertex v0, as a member of C1.

modeled as simple, prismatic voids or more complex shapes, e.g. recessed windows (Fig. 4).

Reading the IFC file.

A preparatory procedure is developed which translates the IFC2x3 model scheme, described in the Express language, into a hierarchical class library for Java or C#. This procedure includes four steps. Initially, the current version of the Express scheme is read and walked, by means of an ANTLR parser (http://www.antlr.org/May2008), and an abstract syntax tree structure is generated. Then, by traversing the tree structure, information concerning data types, enumerations, selects and entities is stored in a set of IFC classes. Subsequently, an code generator was developed, which translates the newly generated IFC classes into a Java or C# class library. Finally, a dispatch table is generated, defining a constructor call for each class. By developing this procedure, a generic tool is created by which each new version of the IFC model scheme can be translated into a Java or C# class library.

Reading a specific IFC file comes down to mapping each IFC entity on the related C# class and, by using the dispatch table, calling the corresponding constructor which recursively generates the related objects.

4.1 *Processing the data*

All IFC objects in memory are analyzed and the useful data is exported to an XML file, describing the construction component geometry and used material layers in a space based structure. The EPW calculation procedure starts from this XML input file. This file format was introduced to enable not only the import of model files based on IFC data format, but also using other formats as a data provider, e.g. the GbXML data format, supported by the Demeter

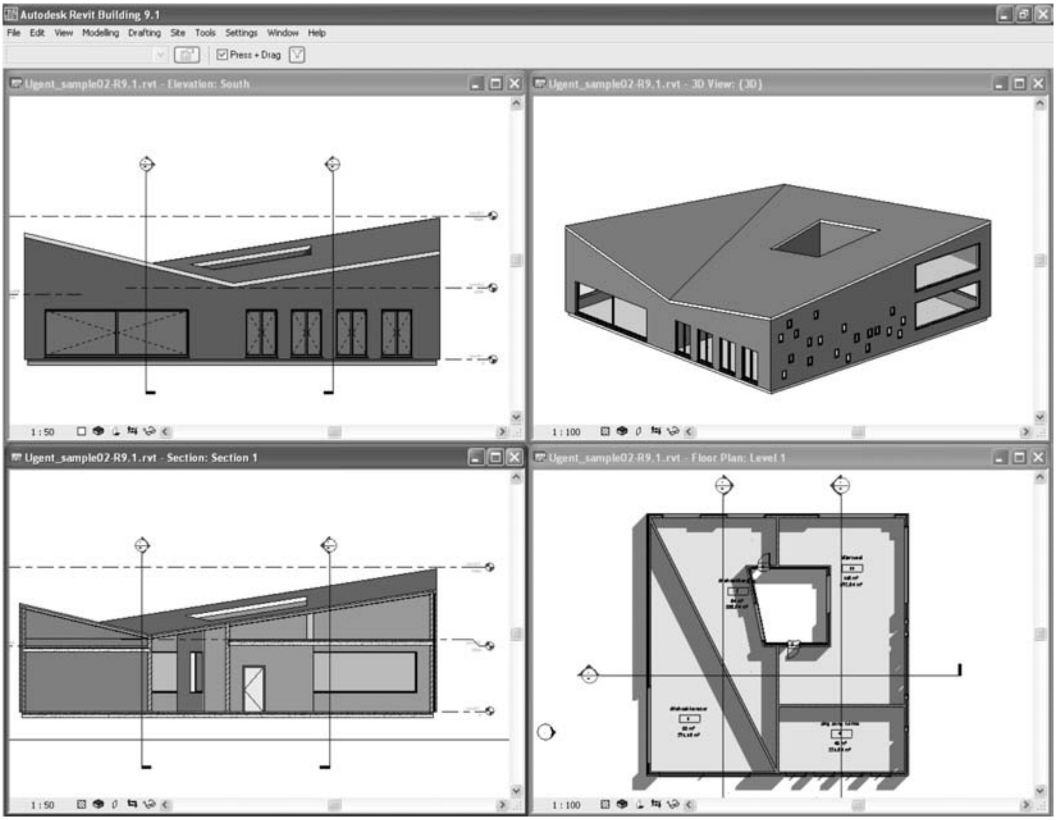

Figure 4. Office building design in Autodesk Revit 9.

plug in for Google SketchUp (http://www.greenspace research.com/demeter_tutorial2.html May2008). Next, the interior and exterior space boundaries are computed as described in the previous sections.

Although in the IFC model the possibility exist to describe a material by its physical properties, or add an external reference, in practice, nothing more than visualization properties can be found in IFC representations. An internal material database is introduced to overcome this problem, supplying, among others, the thermal properties. Once a material or material layer exists in the database it will be automatically attributed to its corresponding construction component, meaning that the assignment is a non-recurrent user intervention.

4.2 *User Interface*

The user interface consists of five views. The first is a view which enables the user to brows the project by means of a tree structure, displaying all components in a space-based structure. A construction component missing a specified material layer or material layer set will therefore be indicated with a dedicated icon. Objects higher in the hierarchy, depending on the incomplete component, are indicated accordingly. The material layer assignment is crucial for the calculation to start, therefore a view by which the material library is accessed is introduced. Additionally, three-dimensional views are provided, enabling the user to check for possible misinterpretations on behalf of the model geometry. Since both internal as external geometry are essential, both are rendered in separate views (Fig. 5).

Finally, the results are displayed in the data view, enabling the designer to evaluate the model and look for possible design ameliorations.

5 CONCLUSION

In this exploratory research project the feasibility to exchange IFC model data between Autodesk Revit9.1 and the Flemish EPW method is investigated, resulting in a software prototype which successfully illustrates the objectives. Several issues regarding the need for a

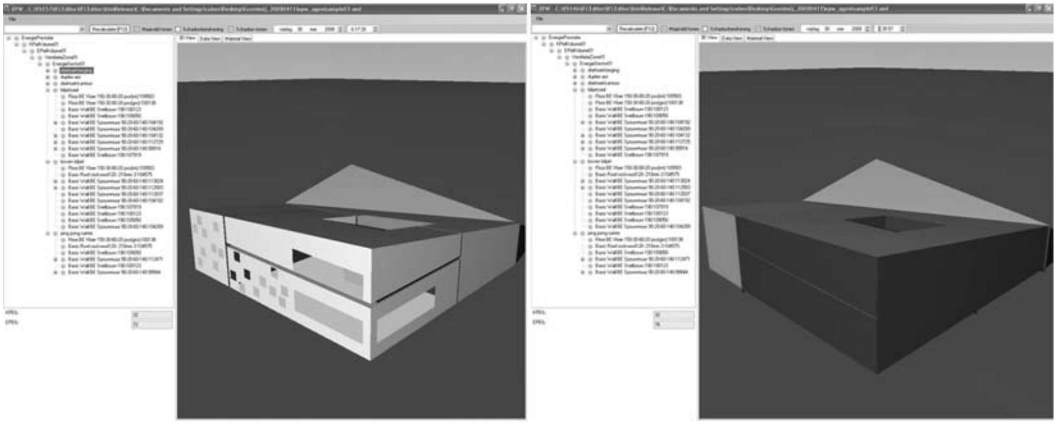

Figure 5. Prototype EPW application, 3D view on internal and external geometry.

space-based building model are identified and algorithms are developed to overcome possible shortcomings. This research can be further expanded to address space based design methods and representations. The supply of a space based building model by the source application could be strongly ameliorated by the exact three dimensional representation of spaces and the mandatory use of more explicit IFC entities, such as curve-like descriptions for the connection geometry instances.

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Methodologies, repositories and ICT-based applications for eRegulations & code compliance checking

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Towards an ontology-based approach for formalizing expert knowledge in the conformity-checking model in construction

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ABSTRACT: This paper gives an overview of a formal ontological approach for formalizing expert knowledge in the context of the conformity checking model in construction. We start from introducing our conformity checking model that aims to (semi)automate the process of the checking of the conformity of a construction project against a set of technical construction norms. In order to enrich this model by integrating the expert knowledge guiding the conformity process, we propose a four-level knowledge capitalization method. First, we model construction norms as a set of conformity queries and develop special semantic annotations of these queries. Second, we organize them into a query base and formulate a set of (semi)formal expert rules aiming at scheduling checking operations. Third, we propose a method to integrate the context-related knowledge on non-formalized construction practices into our model, and fourth, we develop an approach to validate it by usage. Finally, we describe the C3R prototype that illustrates our model by focusing on its knowledge formalization components.

1 INTRODUCTION

This paper presents a formal ontological approach for formalizing expert knowledge in the conformity checking model. This work is developed under the initiative of the conceptual modeling for domain information and knowledge integration for the construction industry.

The complexity of the conformity checking problem can be explained by the multidisciplinary of the components and characteristics defining the conformity checking (e.g. modeling of construction regulations, reasoning on conformity), the large amount of the non formalised expert knowledge guiding the process, as well as the great volumes of construction data to be retrieved and maintained. For all these reasons it is a challenge to propose a method of (semi)automating the process of checking the conformity of a construction project against a set of technical construction rules.

Today, the construction industry is regulated by a large amount of complex rules and regulations that define the conception and execution of a construction product and its components throughout its lifecycle. Their current representations are however still mostly paper-based (e.g. texts, plans) and require a human interpretation to be accessible and interoperable for (semi)automatic construction checking (Lima et al. 2006). The expert's knowledge turns out to be a necessary component to apply them on practice for automated elaboration and validation operations. Despite the huge amount of ongoing works on the implementation of electronic regulation services– OntoGov[1], e-POWER[2], ISTforCE[3], the Singapore ePlanChecking[4], SMARTcodes™[5] – the nowadays available representations of technical construction norms still cannot be directly applied for modeling the conformity reasoning in construction. These projects are not specifically oriented conformity checking and/or focus only on explicit construction knowledge. For this reason, we also develop formal semantic representations of conformity queries integrating checking-related expert knowledge.

Construction projects are commonly represented in the IFC[6] model, the standard for Building Information

[1] http://www.ontogov.com/

[2] http://www.lri.jur.uva.nl/∼epower/

[3] http://istforce.eu-project.info/

[4] http://www.aec3.com/5/5_006_ePlan.htm

[5] http://www.iccsafe.org/SMARTcodes

[6] Industry Foundation Classes, defined at http://www.iai-international.org/

Modeling. Defined with the help of the EXPRESS[7] language (ISO 10303-11:1994), the IFC model allows an EXPRESS-based or an equivalent XML representation of a construction project (in the ifcXML language). In general case, the ifcXML representation of a construction project describes more information than it is necessary for a specific goal of construction checking. From the other side, the IFC model is not enough to represent the whole semantic complexity of the construction data that is really used in the conformity checking process: it does not contain, for example, the information on the functionality of a room (e.g. kitchen). For this reason, our work intentionally dwells within the scope of this practical need: to propose semantically rich project representations for an effective checking of its conformity against technical construction rules and constraints. To do this, we focus on the development of an *intelligent* representation of construction projects for the specific needs of conformity checking. To do this, we adapt the OWL notation approach for the IFC (Beetz et al. 2005), the research of (Yang & Zhang 2006) aiming the construction of application-oriented ontology, as well as the ontology-oriented conversion tools for the IFC standard (Schevers & Drogemuller 2005).

The conformity-checking process is also characterized by a large amount of tacit knowledge: context interpretation of construction norms, checking practices and common expert knowledge, which is *de facto* applied by domain experts. It is also interesting to integrate the usage-based knowledge on effective checking practices (e.g. when a user is checking the conformity of a *door*, s/he will probably check the *accessibility of all entrances*).

The particular interest represents the capitalisation of *domain* tacit knowledge to support implicit semantics on construction domain and the organisation of different types of expert knowledge for further reasoning. To our knowledge, this research axe is innovative for the problem of conformity checking modeling in construction. This work of (semi)formalisation of expert knowledge to be integrated to the conformity-checking model continues our research on the capitalisation of the domain knowledge (Yurchyshyna et al, 2008a, 2008b).

Finally, we study the problem of formalising the knowledge characterising checking practices in different environments. In fact, the checking model should be general enough to integrate the knowledge acquired from different activities of building practices, and at the same time rather specific to be used by a range of final users (building designers and non-professional users). These *know-how* practices in construction are described in application-oriented publications (e.g. EMCBE consultation paper[8]) and thematic Practical Guides[9], edited by CSTB. Our work on the formalisation of these practices is also largely based on the interaction with construction experts: architects, conformity-checking engineers and regulation experts.

By integrating these different types of knowledge, our conformity-checking model groups three main scientific axes. First, we develop a *knowledge acquisition method* to represent all the knowledge involved in the conformity checking process (which includes the formalization of conformity queries for conformity checking and the development of an intelligent checking-oriented representation of a construction project). Second, we propose an ontology-based approach for modeling the *conformity checking reasoning*, which corresponds to the research of validation of knowledge bases. Third, we develop a three-level *knowledge capitalization method*. It allows: (i) to develop special semantic annotations of conformity queries and organize them into a query base, (ii) to formulate expert rules guiding the checking process itself: the "know-how" of construction experts, (iii) to formalize context-related domain knowledge, (iv) to validate the model by usage.

The paper is organized as follows. In next section, we present the knowledge acquisition method that helps to "prepare" the initial data (construction project, technical norms) for reasoning. Section 3 describes our reasoning model aiming to check the conformity of a construction project against a set of conformity queries. The method of the capitalization of expert domain knowledge is detailed in section 4. Section 5 is devoted to the prototype of our model. Finally, we describe the ongoing works and the perspectives of our research.

2 KNOWLEDGE ACQUISITION METHOD

We base upon the Semantic Web languages (Berners-Lee 2001) (RDF/S, OWL, SPARQL) for representing all the knowledge participating in the conformity checking process: a construction project, conformity constraints representing conformity technical norms and a corresponding conformity-checking ontology. The choice of such knowledge representation formalism is explained by the following advantages: (i) it is compliant to the initial ifcXML data format of a construction project; (ii) it is semantically expressive; (iii) it allows developing an RDF-based reasoning model based on graph homomorphism; (iv) it easily interoperates with other semantic resources.

[7] a conceptual language of product data modeling specified in part 11 of standard STEP

[8] http://www.communities.gov.uk/planningandbuilding/

[9] http://www.cstb.fr/actualites/webzine/

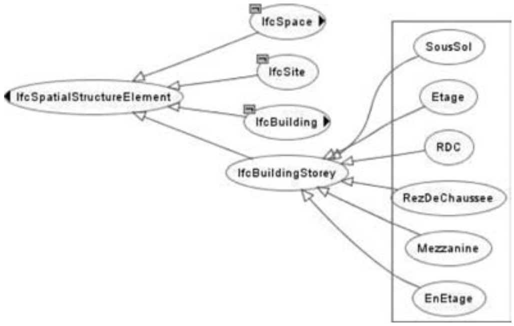

Figure 1. Example of IfcSpacialStructureElement subclasses.

Our knowledge acquisition method is detailed in (Yurchyshyna et al. 2008a). It allows representing all the knowledge involved in the conformity-checking process and making it applicable for conformity reasoning. It is comprises three main phases: (i) semi-automated construction of an ontology oriented conformity checking; (ii) formal representation of technical construction norms; (iii) development of a checking-oriented construction project representation.

2.1 *Construction of conformity-checking ontology*

Our work on the construction of an ontology oriented conformity checking in construction, so called conformity-checking ontology, is based on the variety of works aiming the development of expressive building-oriented ontologies: e-COGNOS (El-Diraby et al. 2003), ifcOWL (Gehre & Katranuschkov 2007), building SMART (Bell & Bjorkhaug 2006). However, we cannot use these ontologies *as is*: they are not particularly oriented the accessibility checking problematic and/or correspond to previous versions of IFC specifications. For this reason, we construct our conformity-checking ontology on the basis of the latest version of the IFC model (IFC2x3 EXPRESS specifications) and according to the concepts which can be found in the conformity constraints to be checked.

To organise the IFC entities as hierarchies and describe them in the OWL-Lite language, we adapt the approach of (Gehre & Katranuschkov 2007) and modify it in order to define new non-IFC concepts and properties (Fig.1).

The conformity-checking ontology is enriched by non-IFC concepts, which are defined with the help of domain experts. They formulate new non-IFC concepts as subclasses of the classes of the acquired IFC-based ontology and/or to formulate explicit definition rules (Fig. 2).

In this example, *GroundFloor* class is defined by a resource of type IfcBuildingStorey situated on the level of entering into a building.

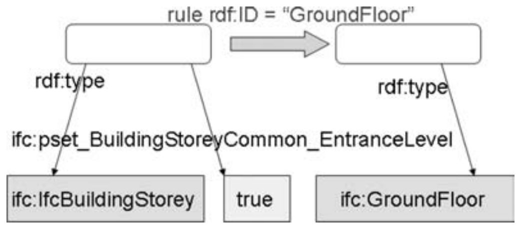

Figure 2. Definition of a "GroundFloor" concept.

2.2 *Formal representation of construction norms*

In the context of our research, we develop a base of conformity constraints that we use to validate our model. To do this, we explore the CD REEF, the electronic encyclopedia of construction regulation texts, and define 9 regulation texts concerning the accessibility of disabled persons. On the base of these documents, we then extract a set of textual constraints and analyze the possibility of their formalization. Thus, we have identified a base of about 100 accessibility constraints to be formalized. We propose to formalize them as SPARQL queries based on the conformity checking ontology.

It is important to note that the problem of knowledge extraction from *textual norms* is, however, out of the scope of our reasoning-oriented modeling. That is why; we do not particularly focus on it. Once identified, the accessibility constraints were formalized as SPARQL queries manually with the help of CSTB experts.

In general, a construction regulation can be modeled as a set of simple queries representing two main types of conformity constraints. First, there are constraints to be always checked: "*The minimum width of an elevator is 1 m*". This constraint is modeled by the SPARQL query (*elevator* concept is defined in the conformity-checking ontology):

```
select ?elev display xml
where
{
?elev ascenseur rdf:type ifc:Elevator
OPTIONAL
{
?elev ifc:overallWidth ?width
FILTER ( xsd:integer(?width) >= 100)
}
FILTER (! bound( ?width) )
}
```

Second, there are constraints that should be checked only under certain conditions. For example, the checking of a constraint "*In the buildings with several entrance halls, all entrance halls should be accessible*" implies two checking operations:

(i) checking the positive constraint of the application condition "*building having at least one* *entrance hall*", formalised by a positive SPARQL query:

```
select ?building where
{
?building rdf:type ifc:ifcBuilding
?building ifc:containsElement ?hall
?hall rfd:type ifc:EntranceHall
}
```

(ii) if this constraint is fulfilled, checking the accessibility of "*entrance hall*", formalised by a negative SPARQL query

```
select ?building display rdf where
{
?building rdf:type ifc:IfcBuilding
OPTIONAL
{
?building ifc:containsCorresponding
Element ?hall
FILTER (?hall =
ifc:AccessibleEntranceHall)
}
FILTER (! bound(?hall) )
}
```

2.3 *Development of a checking-oriented construction project representation*

The developed conformity-checking ontology also guides the process of the extraction of a *useful* representation of a construction project: the one that is oriented conformity checking. This is done by XSLT transformation of the initial ifcXML representation of a project according to the concepts related to the conformity-checking ontology, which are found in conformity queries. The concerned data is extracted from the ifcXML project description and organized as RDF triples. All other data will be useless for conformity checking and thus won't be added to the acquired RDF representation of a construction project.

The acquired RDF is then enriched with eventual non-IFC concepts related to conformity queries. This is done by the consecutive application of the previously defined rules that generate new knowledge for conformity checking task. For example, a project representation is enriched by a *GroundFloor* rule defined by its initial IFC-based data: IfcBuildingStorey, etc. (Fig. 3).

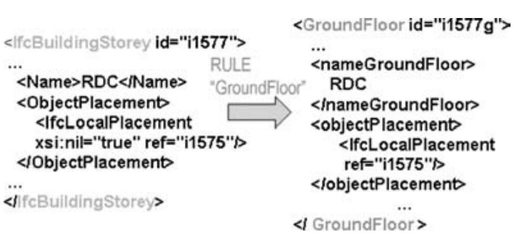

Figure 3. Definition of a "GroundFloor" concept.

As result, the acquired RDF representation of a construction project is (i) defined in terms of the conformity checking ontology, (ii) aligned to construction queries, (iii) not redundant, (iv) enriched by non-IFC concepts concerning conformity.

3 CONFORMITY CHECKING REASONING

Our reasoning model on checking the conformity of a construction project against construction norms is based on the graph homomorphism approach: the matching of norm representations with representations of the construction project.

3.1 *Validation by projection*

In our previous work (Yurchyshyna et al. 2008b), we make a parallel between the problem of conformity checking and the validation of knowledge bases (Leclère & Trichet 2000) that is constructed according to the Conceptual Graphs model (Sowa 1984).

Our choice of Conceptual Graphs as the operational formalism for the conformity checking problem is based on the similarity between RDF/S and Conceptual Graphs, as stated in (Berners-Lee 2001), (Corby et al. 2007). Indeed, as the result of our knowledge acquisition method, we have acquired RDF representations of a construction project and SPARQL conformity queries. They form the basis for the corresponding conceptual graphs, and the reasoning operation corresponds to the homomorphism of these graphs. For the projection itself we adapt a semantic engine CORESE[10] (Corby &, Faron-Zucker 2006). It is an RDF engine based on Conceptual Graphs that enables the processing of RDFS, OWL Lite and RDF statements relying on a CG formalism and performs SPARQL Queries over RDF graphs.

The possible results of the validation process can be interpreted as follows:

- a query can be applied to a construction project if there is a projection from the graph of its application condition to the graph of a project;
- a project is *conform* to a query, if there is no projection of the SPARQL representation of this *non-conformity* query into the RDF of the project;
- a projection is found for some elements, which cause the *non-conformity* of the project against this query;
- if a semantic engine takes into account the semantic closeness of the concepts (e.g. door/entrance), the projection could be partial;
- a projection cannot be established, if the RDF of the project does not contain enough information, which is "asked" by the query.

[10] Conceptual Resource Search Engine, available at http://www-sop.inria.fr/acacia/soft/corese

3.2 *Generation of a conformity report*

The results of the validation process are generated as XML files and interpreted in construction conformity terms: a project is (i) conform; (ii) non-conform; (iii) non-verifiable against a set of chosen queries. These validation results are communicated to a final user as a structured conformity report that is automatically generated with the help of XSLT style sheet applied to XML-based results of the validation process. For each query, the report indicates its success or failure and, if necessary and details the elements causing the non-conformity. When the representation of a construction project does not contain enough information for a match, the conformity report also indicates the lacking elements, which are defined from the pattern sub graphs of the query that cannot be matched (e.g. the destination of a room).

4 CAPITALIZATION OF EXPERT KNOWLEDGE

In this section, we present our four-level knowledge capitalization method aimed to capitalize context-oriented expert knowledge and to integrate it into our conformity-checking model.

4.1 *Semantic annotation of conformity queries*

In section 2.2, we described our approach of formalizing conformity constraints by SPARQL queries. However, this approach does not allow taking into consideration the knowledge that is eventually used in the conformity checking process, but can be hardly extracted from technical conformity norms. This is, for example, the type of regulation texts, the application context of the conformity query, the extraction characteristics of a query (article and paragraph), etc.

In order to integrate this particular knowledge into our checking model, we propose to develop special RDF annotations of conformity queries (Fig. 4).

These semantic annotations combine two main methods of document annotation (Mokhtari & Dieng-Kuntz 2008): the annotation by external sources of

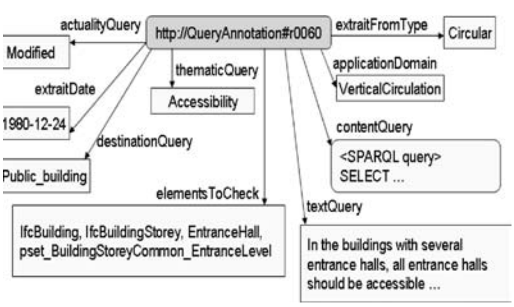

Figure 4. Example of a RDF semantic annotation of a query.

the document and the annotation by content of the document.

The annotation of a query according to *external sources* allows representing different types of knowledge.

First, these are the characteristics of the regulation text from which the query was extracted:

- thematic (e.g. accessibility);
- regulation type (e.g. circular);
- complex title composed of the title, publication date, references, etc.;
- level of application (e.g. national),
- destination of a building (e.g. private house).

Second, they are the characteristics of the extraction process:

- article,
- paragraph from which a query was extracted,
- current number (e.g. the 3rd query of the 1st paragraph of the *Door* article).

Third, we interest in integrating some expert knowledge on this conformity query that could be easily formalized. It is tacit ≪common knowledge≫ on the process of conformity-checking that is commonly applied by domain experts:

- knowledge on domain and sub domain of the application of a query (e.g. Stairs);
- knowledge on checking practice (e.g. if a room is *adapted*, it is always *accessible*)

Fourth, it is important to integrate the knowledge on the application context of a query. This group specifies the aspects of query application for certain use cases. For example, the requirements on the maximal height of stairs handrail vary from 96 cm (for adults) to 76 cm (for kids). In this case, it is important to know the destination of a building (e.g. school).

Characteristics and possible values of the first two groups are automatically extracted from the CD REEF. The knowledge described by the last two groups is defined partially and/or has to be explicitly formalised by domain experts.

The annotation of a query according to *its content* allows representing the semantics of this query: a *set of its key concepts* which define what this query is about.

Formally, we define a *key Concept* tag in the RDF annotation of a query, which value is a list of primitive concepts from the conformity-checking ontology extracted from the SPARQL representation of this query. For example, the query "*In the buildings with several entrance halls, all entrance halls should be accessible*" has the following key concepts: IfcBuilding, IfcBuildingStorey, EntranceHall.

These RDF semantic annotations allow representing domain-related knowledge on construction norms that characterize conformity queries. They help to classify the queries, to organize them into a conformity query base and to formalize an *effective* algorithm of expert reasoning.

4.2 *Formalization of expert rules*

The particular interest of our approach is the modeling of *effective* checking that takes into consideration the expert knowledge guiding the conformity checking process. It is the knowledge on the *process* of checking: *how* the checking is done (e.g. checking of physical dimensions of construction elements norms is followed by checking on accessibility). To do it, we propose to first classify conformity queries and to organize them into a query base. Second, we formalize expert rules that define the optimal scheduling of matching procedures.

The organization of the base of conformity queries is based on their semantic classification: the identification of groups of queries "similar" for reasoning. It means that the queries from the same group are treated according to the same expert rules and expert rules defined for different groups of queries can be applied to all queries from these groups.

We have defined 3 types of semantic classification of conformity queries:

- *by construction:* queries are classified according to expert knowledge defining the query (e.g. thematic) by possible values of this criterion (e.g. possible values of thematic are accessibility, acoustic, etc.).
- *by key concepts:* queries are classified according to corresponding key concepts of their semantic annotations. This classification is, in fact, the classification by *specialisation/generalisation relations* existing between the graph patterns of key concepts (e.g. the class concerning a building (public building/three-floor house/school) is defined by IfcBuilding).
- *by application condition:* for queries that should be checked only under certain conditions. It is a classification by *specialisation/generalisation relations* existing between the graph patterns representing the condition of query application (e.g. the application condition of a query "*in school, all doors are* ... " is a specialisation of the application condition of a query "*in public building, all doors are* ... " as the graph representing *school* is the specialisation of the one representing *public building).*

According to these types of semantic classification of conformity queries, we have formalized a set of expert rules. This was done in collaboration with domain experts (from CSTB). These expert rules are applied to *classes* of conformity queries and define the optimal scheduling of their checking.

The first group of expert rules corresponds to the classification of conformity queries *by construction.* The type and possible values of such classification are defined externally: in regulation texts. The scheduling of these queries corresponds to the hierarchy of their classes. The simplified examples of such expert rules are:

- according to the type of regulation text. Identified *classes* are *decrees* and *circulars*. The scheduling corresponds to the explicit hierarchy of regulation texts: *decrees* queries are treated first, and then – *circular* ones.
- according to the application domain. Identified classes are *vertical circulation*, *stairs* and *elevator*. The scheduling is defined and validated by a domain expert: first, *vertical circulation* queries, second, *stairs* and *elevator* queries with the same priority
- according to the regulation text. Identified classes correspond to the titles of regulation texts. The scheduling is defined by a user: e.g. all queries extracted from Circular 82–81 of 4/10/1982.

The second group of expert rules corresponds to the classification of conformity queries by *key concepts*. Queries representing more specialised knowledge are treated in priority. For example, an *entrance door* query is prior to a *door* query (entrance *door* is a specialisation of *door*), because if a construction project is non-conform to the first one, it will be automatically non-conform to the second one.

The third group of expert rules corresponds to the classification by *application condition*. The priority is also reserved for queries, which application condition represents more strict knowledge in comparison with application conditions of other queries. For example, if we interest in the accessibility of a *school*, we should start by checking queries applied to *public building receiving sitting public* and continue by checking more general queries applied to *public building receiving public.*

It is important to underline that the formalization of expert rules and the scheduling of checking procedures imply the modification of our reasoning model and the interpretation of the results of the validation process.

Indeed, the validation process could fail for a new reason: as a result of the application of these expert rules. It corresponds to:

- the queries having little priority of treatment;
- the queries, which graph pattern is more general in comparison to previously failed queries;
- the queries having more general annotations representing the application constraint is in comparison to the annotation of corresponding previously failed queries.

In such cases, the further reasoning is useless (if a construction project is non-conform to more "important"/prior queries, it will be automatically non-conform to less prior queries), unless a final user explicitly indicates the continuation of the validation process.

Consequently, the possible reasons of the non-validation and non-conformity of a construction project are enriched by *non validation according to expert reasoning* that will be also detailed in the conformity report.

4.3 *Context Modeling*

This phase of modeling aims at the capitalization of the context-related knowledge that becomes explicit only during the process of conformity checking: *when* usage practices validate the effectiveness of the proposed model and *why* it does not work for certain types of usage. Generally speaking, this knowledge reflects so-called checking practices: checking in the *application context*. It helps thus to detail certain expert rules and/or to enrich the conformity-checking ontology. For example, if our ontology defines an *entrance door* as "a *door* situated at a *ground floor"*, in practice, it could become evident that this definition should be detailed as follows: "an *entrance door* is an *exterior door* situated at a *ground floor"*.

For modeling of such context-oriented checking, we propose: (i) to enrich our approach of the organisation of conformity queries by *context organisation*, as well as (ii) to define corresponding *context rules* that detail the application of expert rules in different contexts of the conformity checking process. To do that, we introduce the notion of the *checking process context* representing specific conditions of the checking process: *how* to check the conformity in a certain *context.*

Generally speaking, the context can be defined as the information that characterises the interactions between humans, applications and environment (Brézillon 2007) and is expressed by a set of hypotheses that limit the application and/or use of the model. For our problematic of the conformity checking in construction, this can be interpreted as follows: the *conformity-checking context* reflects *typical user scenarios*:

- *what* (e.g. which elements of a construction project) final users are likely to check;
- *how* they search the corresponding queries to precise the type of conformity checking;
- *when* (e.g. scheduling of conformity queries) they continue checking operations;
- *why* they stop checking. This can be explained by several reasons. First, the checking process stops as the answer on the (non)conformity of a project is acquired. Second, final users stop the process as they are satisfied with an acquired partial answer. Third, final users stop checking as they evaluate further checking as useless and/or too expensive.

To answer these questions in terms of our conformity-checking model, we adapt the approach represented in (Hernandez et al. 2007) for modeling two main aspects of the conformity-checking context: (i) themes of the user's information need; (ii) specific data the user is looking for to achieve the task of conformity checking.

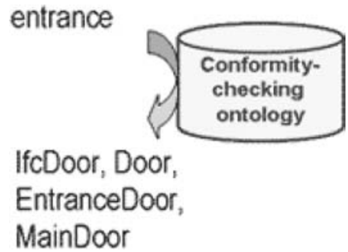

Figure 5. Semantic synonyms of entrance.

To define the user's information need (e.g. check the conformity of entrances of a building), we need first to understand this need: to identify a concept expressing the context of reasoning. To do it, we use the conformity-checking ontology allowing detailing this need (Fig.5: entrance could be defined as door, *front door*, etc.).

The context of reasoning is, therefore, expressed by a set of semantic synonyms of a concept expressing this need. In this example, when the information need of a user is to check the conformity of all *entrances* of a building, the context is defined by semantic synonyms of an *entrance:* a *door*, a *front door*, a *main door*. The conformity checking in this context can be then interpreted as the checking of a construction project against all the queries related to a *door,* a *front door* and a *main door*.

To model the *specific data* the user is looking for *to achieve the task of conformity checking*, we identify the *formal criteria* defining the conformity-checking *context*. These are the characteristics of the checking process, which are *most likely* to be taken into consideration in the checking process. They are, consequently, more likely to be formalized by expert rules.

Currently, we have defined 5 main types of such criteria:

- type of regulation text;
- name of regulation text;
- destination of building;
- application domain;
- key concept (element(s) of a building to be checked).

Our work is now focused on the formalisation of typical construction checking scenarios by formalising hybrid expert rules based on these 5 main context criteria. A schematic example of such hybrid rule is as follows:

- choose destination of a building (e.g. public building) and select the corresponding queries;

– choose thematic (e.g. accessibility) and select the corresponding queries;
– choose elements to check (e.g. entrance door) and select the corresponding queries;
– schedule selected queries according to *type of regulation text* expert rules (e.g. queries extracted from European norms);
– schedule selected queries according to *key concepts* expert rules (e.g. queries which key concepts are: door, width, door materials, luminosity);
– send each class of these queries to the checking engine (for matching operations);
– generate a conformity report for each class of these queries.

4.4 *Validation of the model by usage*

This phase of our method on the capitalization of expert knowledge is devoted to the validation of the model by usage.

According to our knowledge acquisition method, represented in section 2, the conformity-checking ontology is developed independently from the checking process itself. All concepts and relations of the ontology are defined and validated by domain experts. Domain experts also formulate rules of definition of new concepts, context rules and, in general, they validate the whole knowledge base of the conformity-checking process.

However, in some cases, such definitions can be partial or inadequate, and it does not represent the real usage-driven conformity-related knowledge of the checking process: even the definition of domain experts is not sufficient to represent the whole complexity of the checking knowledge.

For this reason, it seems important to propose an approach of the acquisition of another type of the checking knowledge: the knowledge on the checking practices, which turns out explicit thanks to a large number of checking operations by different final non-expert users. This will also help to validate the conformity-checking ontology defined by domain experts by practice. In other words, we propose an approach of the usage-based evaluation of the semantic proximity of different concepts/relations of the conformity-checking ontology.

To illustrate these ideas by an example, let us take three subclasses of IfcDoor: *door*, *entrance* and *entranceDoor*, which are defined equivalent in the conformity-checking ontology. They are also used as key concepts to annotate conformity queries (e.g. these three concepts annotate the query "*an entrance door of any building should be accessible to disabled persons"*). According to our model, for the checking of the conformity of an *entrance door* of a building, a construction project should be checked to the queries annotated by *all these three* concepts. A full list of these queries will be thus proposed to a final user. Sometimes, this list turns out redundant: a final user has no interest in some queries (e.g. the one concerning the *luminosity of an entrance door of a school*). In this case, it seems out interesting to evaluate the cohesion between the queries *chosen* and *rejected* by a final user and the corresponding key concepts annotating these queries. For example, we can notice that queries annotated by *entrance* and *entranceDoor* are chosen more frequently than the ones annotated by *door* concept. Intuitively, *entrance* and *entranceDoor* are semantically closer than *entrance* and *door*.

To propose a formal definition of the validation of the conformity-checking ontology by usage, we first define our approach on the evaluation of the concepts of the conformity-checking ontology. It is based on three main criteria (Karoui et al. 2007) adapted for the conformity-checking problematic:

– *Credibility* degree. We suppose that all concepts and properties of the conformity-checking ontology are defined by construction experts, their definitions are pertinent and correct; the credibility degree is thus equal to 1.
– *Cohesion* degree. To start, we suppose that our conformity-checking ontology is homogeneous: there are subclasses of a class which are declared equivalent by domain experts (e.g. door, entrance, entranceDoor).
– *Eligibility* degree. Concepts/relations are defined by experts and added to the conformity-checking ontology, if they are necessary for the formalization of conformity queries.

Our approach of the *validation* of the conformity-checking ontology *by usage* is developed according to the same criteria, in order to keep the semantic consistency of the conformity-checking ontology:

– *Credibility* degree. No concepts/relations can be defined by final non-expert users. The credibility degree is thus equal to 0.
– *Cohesion* degree. The distance between the equivalent concepts is then recalculated according to the frequency of their simultaneous choice by final non-expert users (e.g. *entrance* and *entranceDoor* are chosen more often).
– *Eligibility degree*. If some classes of semantically close concepts are defined, it can be interesting to identify the concept characterising the whole class: e.g. *entranceDoor* for the class containing *entrance, accessible Entrance, frontDoor, etc.* By identifying the representative concept of the class, we can refine the semantic annotation of the corresponding queries (for example, annotating them only by this concept) and, consequently, the algorithms of expert reasoning (for example, we do not need to schedule queries which are annotated by the concepts of the same class).

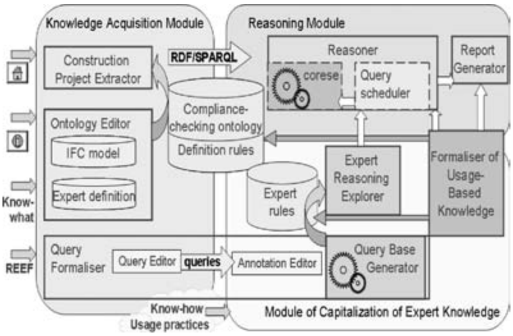

Figure 6. C3R conceptual architecture.

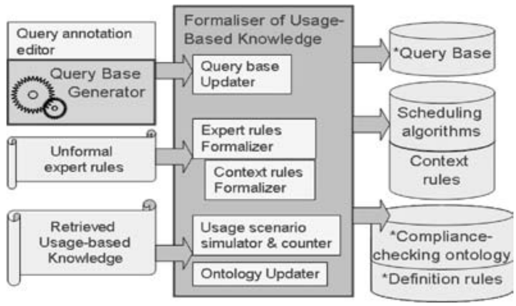

Figure 7. Formalizer of usage-based knowledge.

To model the semantic distances in the conformity-checking ontology, we base on the calculating of the semantic similarity in content-based retrieval systems (El Sayed et al. 2007) and by adapting the approach of the "intelligent evaluation" (Karoui et al. 2007) of ontological concepts. Currently, we work on the detailed development of the conceptual approach for the evaluation of the concepts of the conformity-checking ontology. Our future works will be devoted to its further development and, in perspective, practical evaluation of this approach, which requires an implementation of our conformity-checking model.

5 C3R PROTOTYPE

In order to validate the model by practical usage, we are currently developing the C3R (Conformity Checking in Construction: Reasoning) prototype and the corresponding software.

5.1 *Conceptual architecture*

The C3R prototype implements our conformity-checking approach model and its main components correspond to main components of the model. Its conceptual architecture is represented at Figure 6.

In the context of our work, we particularly interest in the capitalization of usage-based knowledge, which characterizes the conformity checking process (Fig. 7).

It helps, for example, to validate the model by usage and add necessary modifications into the conformity-checking ontology and/or expert rules guiding the checking process.

5.2 *Implementation*

For the C3R prototype, we have defined a conformity-checking ontology that currently has 1780 concepts (about 80% of them are derived from the IFC model, 2×3 specifications, and 20% of them are defined by a domain expert) and 1250 properties (about 85% of them are derived from the IFC model, 2×3 specifications, and 15% of them are (re)defined by domain experts).

To develop a base of conformity queries for the validation of our approach, we have chosen 9 regulation texts on the *accessibility* of *public buildings* (*French* regulation base). They represent different classes of regulation texts: *arrêté, circulaire, décret, norm* and describe the accessibility constraints of different entities: doors, routes, signalisation, etc. With the help of CSTB experts, we have identified about 350 simple text conformity queries that resume these 9 regulation texts. These queries are classified as:

- Verifiable: (i) such queries can be formalized with the help of the conformity-checking ontology; (ii) a construction project representation possesses all the information needed for checking its conformity against these queries
- Partially verifiable: (i) it is necessary to reformulate queries before formalization (e.g. the accessibility of a door is defined by its width); (ii) a construction project representation should be manually completed by the lacking information (e.g. destination of a room);
- Non-verifiable: (i) it is impossible to formalize a query (e.g. it is too abstract); (ii) it is impossible to verify the conformity because of the limitations of the reasoning formalism (graph projection).

In the context of the practical validation of our approach, we have formalised about 75 conformity queries as SPARQL queries (about 20% of them are verifiable and 80% are partially verifiable).

We have also annotated these conformity queries by special RDF annotation that comprises also the information on the regulation text (e.g. Circular n°94–55 of 7/07/1994), the type of checking (e.g. accessibility), the text of a query, the formalized representation of a query, etc. These annotations were developed semi-automatically by extracting the construction information from CD REEF and by manually enriching them with domain information identified by CSTB experts.

The development of the corresponding software application is incremental: the first simple prototype already exists. It is dedicated to conformity checking of a project against a set of non organized accessibility queries. Next versions of the prototype will implement (i) the semantic organization of the queries, (ii) the implementation of expert rules, as well as (iii) the enrichment of the conformity-checking ontology according to the capitalized usage-based knowledge. Each version will be also validated by construction experts of CSTB.

6 CONCLUSIONS AND PERSPECTIVES

We have presented a formal ontology-enabled approach for formalizing expert knowledge in the context of the conformity checking model in construction.

Our model has three main components. We start from introducing our knowledge acquisition method that aims to represent all the knowledge to be used in reasoning. Then, we describe our checking reasoning model based on matching the representations of construction projects and conformity queries. Finally, we concentrate on the knowledge capitalization method that allows formalizing expert rules on the checking process, context-related expert knowledge and validating our model by usage. To illustrate the feasibility of the proposed model, we present the C3R prototype and discuss the details of its development.

In perspective, we continue the further incremental development of the conformity-checking ontology and the C3R prototype, as well as their evaluation by domain experts and final users. In parallel, we enrich our knowledge acquisition method by formalising and structuring tacit expert knowledge, as well as by redefining expert rules of the checking process.

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Modeling and simulation of individually controlled zones in open-plan offices – A case study

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ABSTRACT: Many field studies of office environments show that complete thermal user satisfaction can only be achieved by setting the indoor climate to individual user preferences. Most open-plan offices do not support this requirement. In addition, irregular occupancy of such offices leads to sub-optimal energy usage. This paper will show how the design of such offices can be supported by tools that integrate individual thermal user preferences and schedules into performance simulations to test and evaluate different partitioning structures, HVAC equipment, and control strategies in regard to user satisfaction and energy consumption. A case study is used as demonstrator.

1 INTRODUCTION

Open-plan offices are the standard in many organizations because of the flexibility in regard to reorganizations and other advantages. A major disadvantage is that the thermal climate in open-plan offices is very difficult to control in small zones. Therefore, large open-plan offices are typically controlled as one zone with the goal to provide a uniform indoor climate.

Many laboratory and field studies have been conducted to define the optimal thermal parameters that provide a maximum in user comfort while minimizing energy consumption. The results have been published as ASHRAE-Standard 55-1992 and as ISO 7730-1994. They define the optimal relation between air and radiation temperature and relative humidity, called the effective temperature *ET*. Theoretically, compliance with the standard should guarantee 95% user satisfaction.

A large body of field studies that measured the thermal conditions directly at individual workplaces and correlated the results with questionnaires of office workers at these workplaces show a much lower satisfaction level, typically between 50 and 80%. This result is to a large extent independent of the compliance with the standard. With our current technology level in HVAC equipment and control systems it is unacceptable to design and build offices with such a low level of user comfort.

A second problem of the large control zones of open plan offices is the energy consumption. In most organizations office work hours no longer start at 8:00 and end at 17:00, for example. Work hours are much more flexible, in the extreme, offices are partly occupied during the nights and on weekends. For the thermal control of open-plan offices this means that the periods for energy-saving set-back times are largely reduced, if comfort conditions are provided whenever a workplace is occupied.

Both problems can only be solved when thermally controlled zones are reduced in size to individual workplaces, and when such *micro-zones* are controlled to the preferences of the individuals and dependent on actual occupancy. This should be the goal of architects and engineers in the layout of open-plan offices, the selected equipment, and the control systems.

At first sight this seems technically impossible. But this is not true. The problem is more that not enough experience exists and gaining experience by trial and error is expensive. The solution we propose is to conduct case studies in real offices and use the results to build models and simulation environments that comply with the measured results and can be used to evaluate different design alternatives for new open-plan offices or for refurbishing existing ones. This is partly demonstrated in the paper. We have access to an open-plan office with adequate HVAC equipment and use this as a case study. We have modeled this office for simulation purposes and will show how far the goals can be achieved, trying different design alternatives. Other variable parameters are weather files, occupancy patterns, thermal user preferences. Selected results will be shown to demonstrate the power of simulation.

2 INDIVIDUAL COMFORT

2.1 *Field studies*

The thermal comfort of individuals is a complex function of different temperatures, humidity, air flow, clothing, metabolic rate and other parameters. Defined is the operative temperature T_o as a linear function of the air temperatures T_a at different heights of the body (0.1, 0.6, 1.0 m above floor) and of the average radiation temperature T_r of the surrounding surfaces. The humid operative temperature T_{oh} is a complex function of T_o and the humidity and determines the heat loss of the skin. The new effective temperature index ET^* is defined as T_{oh} at a relative humidity $rh = 50\%$. In this paper we always refer to ET^* if we show indoor temperature values.

The ISO standard defines the following set points as optimal for summer and winter season:

$$ET^* = 23.5 \pm 1.2°C \ \text{(summer)} \quad (1)$$

$$ET^* = 22.5 \pm 1.2°C \ \text{(winter)} \quad (2)$$

Because of the low satisfaction levels found in office questionnaires, standardized field studies have been conducted world wide and the collected data have been published as a database (ASHRAE-rp884). One detailed analysis (de Dear et al. 1997) led to the definition of an adaptive comfort model with variable comfort temperature ET^*_{comf} based on a sliding average of the outdoor temperatures ET^*_{outd} of n recent days:

$$ET^*_{comf} = 22.6 + \frac{0.04}{n} \cdot \sum_n ET^*_{outd} \Big|_{6am}^{3pm} \quad (3)$$

We have analyzed some of the data from a different perspective. If we assume that each individual has its own personal comfort temperature and range and this even varies with the season and the time of the day, all attempts to find the optimal set points for large control zones must fail.

Different satisfaction scales have been used for the questionnaires. Here, we use the MCI thermal preference scale with only 3 categories: co = *want cooler*, ok = *no change*, wa = *want warmer*. More refined classifications did not show better correlations with the measured parameters. Since the users in the field studies did not have the option to set their own comfort temperatures, we have to make the assumption that the reported temperatures are closely correlated with the preferred temperatures in the case of reported ok-values. The other two categories should be interpreted according to their meaning.

For the purpose of demonstration we have selected a summer and a winter case study. The first was conducted in Montreal in the summers of 1994/95 with 453 individuals. Under the given temperatures of an air conditioned building, 53% wanted no change, 32% wanted cooler, and 15% wanted warmer temperatures. Figure 1 shows the frequency distributions of the three categories in the temperature ranges. In this case there is a strong correlation between the wanted change and the average temperature, but still a stronger overlap of the ranges in the three categories. The most striking result is the wide range of temperatures felt satisfying. If we assume that this range is not due to the wide tolerance range of the individuals, this range clearly means that in order to provide comfortable temperatures in an office with many individuals, a set point range of 21 to 26°C has to be realized for each workplace during the summer season.

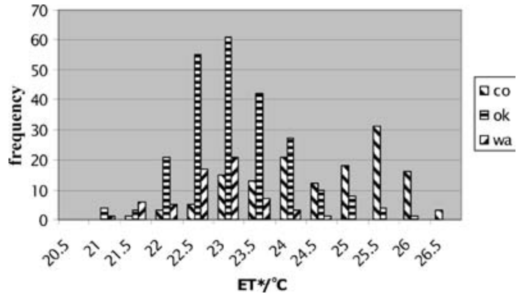

Figure 1. Frequency distribution of office temperatures during the summer in Montreal for three different thermal preference categories.

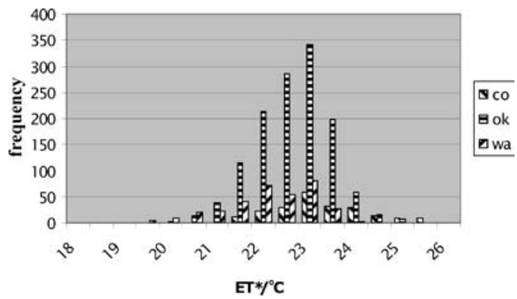

Figure 2. Frequency distribution of office temperatures during the winter in Ottawa for three different thermal preference categories.

Despite computer controlled air conditioning, the spread of measured temperatures is large. This could be a reason for the low acceptance rate of 53%. If we look at the temperature of 23°C which a maximum of users found ok, the acceptance rate is 63%. This is still much lower than the 95% predicted by the standards. As a conclusion we have to accept that there is no standard temperature which can satisfy nearly 100% of the office workers.

Figure 2 shows the same distribution for offices in Ottawa in the winter of 1994/1995 with 1859 individuals. The temperature range for individuals voting ok is 18.5 to 25.5 with a majority vote for 23°C. This means that for the Canadian climate summer and winter shows no significant difference in the preferred temperature setting. Surprisingly, in this case the majority votes for *want warmer* and *want cooler* shows 23°C as well. This finding supports the assumption that individual preferences are much more important than standard settings.

2.2 *Satisfaction model*

Since the satisfaction model underlying the standards that predicts the *percentage of dissatisfied persons* (PPD) as a function of the *predicted mean vote* (PMV) (Fanger 1970) could not be validated by the reported field studies, we will define our own satisfaction model to be able to evaluate satisfaction levels *sat* from simulation experiment results. In order to simplify the evaluation, we propose a cosine law:

$$sat = \cos((T_p - ET^*) \cdot rt \cdot 0.5 \cdot \pi) \text{for}\, ET^* \pm rt, = 0 \,\text{else} \tag{4}$$

Tp means individually preferred temperature
rt means tolerance range

Satisfaction is assumed if the temperature ET^* is within 0.5 *rt* of *Tp*. This means $sat > 0.71$. The design and maintenance goal of open-plan offices should be to approach $sat = 1$ for the individual and the satisfaction $satA = 1$ averaged over all occupants.

As a second satisfaction measure we calculate the percentage of time *satT* during which the temperature ET^* is within the satisfaction range. Both measures will be used in the results chapter.

3 OCCUPANCY

3.1 *Field studies*

Several field studies of office occupancy levels have been conducted for different purposes. Two such studies (Mohammadi et al. 2007, Larnbeva & Mahdavi 2007) evaluated how individuals control artificial and natural light. Video observation results show also that individual workplaces have a maximum occupancy level of less than 60% during a time range of 6:00 to 20:00 hours.

Another field study in university offices was conducted to model and simulate space utilization (Tabak 2008). The data are based on many years of questionnaires of university employees and partly verified with RFID tags. The result is a software tool USSU that generates individual schedules of personal and job related tasks in relation to workplace positions and other locations. It also provides routing through public spaces and trip times.

We have conducted simple questionnaires about the work habits in the university office IWS we use for the case study (see Chapter 5.1).

3.2 *Occupancy model*

For our simulation purposes we created a scheduling model for individuals, jobs, and workplaces. Each individual determines the times for taking and quitting a job in the office. The times are based on preferred averages and random ranges. The individuals also determine the times for personal breaks, randomly based on frequencies. When a job is taken, this determines all job related schedules and workplaces. Primary tasks are classified as regular (classes, meetings) and irregular (at hoc meetings). Some secondary tasks such as *go to printer* are triggered by primary tasks. We assume that office occupants conduct a main task at their desk whenever the other tasks leave some time. This seems typical for many jobs. Preferred environmental parameters such as thermal properties, light levels, or noise depend on the individual and the task. Both influences are propagated to the workplaces together with occupancy data and from there to the control systems.

These features have been modeled and implemented in a multi-agent system (Zimmermann 2007). The system reads individual and job related parameters from files. For the purpose of the current case study that is performed using the commercial performance simulation environment TRNSYS™, a simplified model had to be re-implemented in MATLAB™. If a space is occupied at a time by more than one occupant, the preferred temperatures and tolerance ranges are averaged.

4 MICRO-ZONE CLIMATE CONTROL

Climate control in buildings with HVAC is governed by zones. The zone control provides a uniform indoor climate throughout the zone. If many persons share a zone, no individual climate control is possible. Even in buildings with private offices, typically many offices share the same control zone.

If we have the goal to provide each personal workplace with its preferred climate, the zones have to be reduced in size to the dimensions of workplace areas (micro-zones). One commercial solution is the Johnson Controls Personal Environmental Module™ (PEM). It consists of a desk with, as one of the features, outlets for air with individually controlled temperature (within limits) and flow from the central HVAC system. The air is supplied with flexible ducts from a raised floor.

Another technique that is in use is the individual control of the air volume of overhead air outlets by VAV boxes (Jelsma et al. 2002). The warm or cold air is supplied by a central HVAC system. The size of such a zone covers about four office workplaces. In some cases the VAV boxes also provide an electrical reheating capability if the supplied air is too cold for some office areas. The latter is a very inefficient use of energy.

Supply of hot and chilled water for the climate control of small zones is a better option. Fan coil units under a raised floor, in the ceiling or even hanging under the ceiling (Coolwave™) can control recycled air and water flow for heating and cooling of micro-zones. In humid climates, these systems have to be complimented by central dehumidification systems that also provide fresh air, but with a tenth of the air flow necessary for HVAC.

A third technique is based on heated or cooled radiative panels at walls or ceilings to influence the operative temperature t_o without changing t_a. Supply for these panels is typically hot or chilled water which can be locally controlled.

Prerequisite for all these techniques are local controllers in each micro-zone, preferably with user interaction for setting ET^* and feedback of consequences of the settings to the user. Global controllers are also necessary because adjacent zones in open-plan offices interact with each other thermally to a large degree. This interaction has to be taken into account and is part of our field study.

5 THE FIELD STUDY

5.1 *The testbed*

In order to be able to make experiments with tangible results, the "Robert L. Preger Intelligent Workplace" open-plan office (IW) at the Carnegy Mellon University, Pittsburgh has been chosen (IW-homepage), built and used by the Centre for Building Performance and Diagnostics (CBPD). The IWS is a rectangular section of 25×10 m with windows on three sides and open to the rest of the IW. Defined by the roof structure, the length of the space in divided into 5 bays. Each bay is divided into 2 work spaces on the east and west window fronts with a hallway space in between (see Fig. 3).

The ceiling height is 3 m between and 3 m to 5 m in the bays. The partitions between the spaces consist of cabinets, bookshelves, office partition walls of different heights, plants, and other elements. The height of the partitions ranges between 1 m and 2.5 m.

Space s2 is a meeting place, the 9 offices are shared by 4 faculty members, 4 visitors and 12 students. All spaces but the hallways will be equipped with space controllers that control the fan coil units under the raised floor. All spaces are equipped with water mullions that run vertically between the window panes to compensate radiation effects of the windows. Humidity controlled fresh air is provided by a central air handling unit. So far, the mullions and the central air supply are functioning in all 10 spaces, fan coil units are currently installed in two spaces. These two and the adjacent spaces are equipped with a network of temperature sensors for the calibration of the simulation model and for control experiments.

5.2 *The building model*

The building model uses the TRNSYS™ simulation and modeling Studio. This system provides a module for multiple zones in a rectilinear 3D grid. In compliance with this structure we defined 10 office spaces, 5 hall spaces, and 4 adjacent spaces (n3, n4, h0, h6 in Figure 3) with 15 plenum spaces below and a flat roof at 3m above the raised floor. This deviation form the roof structure of the IWS simplifies the model. Outdoor wall and roof segments are aluminum/insulation sandwiches with a load bearing steel structures on the inside. All windows are thermopane. In principle, walls and roof have low heat storage capacitances, but the steel structures add a large capacitance. As a simplification we modeled the steel weight as an 11mm steel layer on the inside of the roof. The raised floor tiles above the plenum are made from concrete with a carpet on top and add another large heat capacitance. All this together with the furniture creates a rather slow temperature response. To reach steady state after heat flow changes, we had to use simulation intervals of up to four days.

Figure 4 shows the heat flows hf1 ... hf10 of a space from or to its adjacent spaces and the internal heat sources hs1 and hs2. We have set the adjacent spaces n3, n4, h0, h6, and the 15 plenum spaces to constant temperatures. They can be varied as experiment parameters. The measured high plenum temperature is due to several ducts and pipes in the plenum. For the outdoor environment we use the standard weather

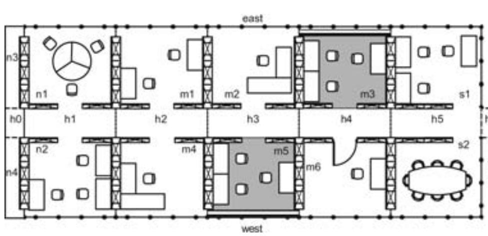

Figure 3. Layout of IWS. The shaded areas are currently equipped with fan coil units.

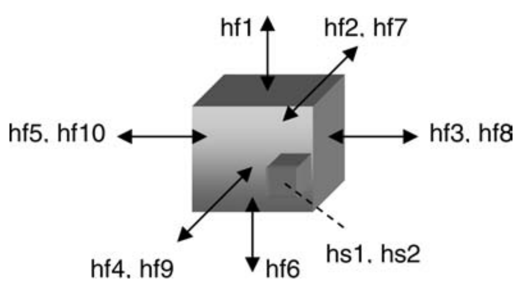

Figure 4. Heat flows and sources of one office space.

file for the city of Pittsburgh, USA. We also created artificial weather files with constant temperatures and no solar radiation. With the artificial files we can produce results with shorter simulation periods than full year data and these results are easier to interpret. Table 1 lists the different heat flows, sources, and models.

Heat flows hf1 to hf7 are based on standard models and fully supported by TRNSYS. The only uncertainty is the thermal resistance of furniture elements used as partitions between spaces (hf3 to hf5). In the IWS a large range of different types exists, giving a personal note to each space. Since these heat flows play a minor role in the heat exchange between spaces, we have modeled all of them as solid walls with identical thermal properties.

The major heat flows hf8 to hf10 between spaces need more consideration. In TRNSYS air flows between spaces are called *coupling* with the air flow as parameter. Symmetric flows are assumed. This air exchange through openings depends on many geometric factors and other parameters. In principle this would require cfd simulations with exact space and furniture geometries. These are very time consuming and sensitive to minor changes in the analyzed spaces. We accepted a larger error at this point by using models for air exchange through open windows in the case of no wind pressure differences. These models assume still air and are based on barometric pressure difference caused by temperature differences in the adjacent spaces. The mass flow *fla* in kg/h is calculated according to (ASHRAE 2001) as

$$fla = 4320 \cdot a \cdot eo \cdot (abs(T_i - T_j))^{0.5} \quad (5)$$

a is a factor that according to different publications ranges between 0.005 and 0.01. We are using according to (ASHRAE 2001) $a = 0.01$, although measurements in the IWS suggest a larger value. This may be due to the air movements caused by the fan coil units. We do not have enough measurements at this point to propose a value.

eo means effective opening and is calculated as

$$eo = w \cdot h^{1.5} \quad (6)$$

w is the with of the opening in m

h is the height of the opening in m

If several openings of different widths w_i and heights h_i exist in one partition wall, the effective openings can be added:

$$eo = \sum_i w_i \cdot h_i^{1.5} \quad (7)$$

T_i and T_j are the air temperatures of the adjacent spaces *i* and *j*.

The heat flow *hs1* is modeled as ventilation with the parameters air exchange rate and air temperature, both within the limits of the specifications of the used fan coil units and set by the control algorithm. The air temperature is limited by the hot and cold water supply temperatures, in the case study 30°C and 10°C. The air exchange rate is limited by the maximum air volume rate of the fan coil units. We have assumed 3 units of type VKB630™ (LTG AG, Stuttgart) per space with 450 m^3/h each and fixed the air exchange rate below this value at 14 exchanges/h.

This model is a simplification because the dynamic behavior of fan coil units is much more complicated. It depends on the supply pump pressure or flow, the supply piping dimensions and layout, the valve characteristics, the layout of the heat exchangers and other factors. For the purpose of this study such details are of secondary importance, but have to be taken into account when the results shall be compared with measured data.

In TRNSYS, several controllers are supplied. We used modules called "Equation" instead to have full control over the algorithms. After trying pid and other controllers, we settled for a p-controller with upper and lower limits and a swing range (range of temperatures between two set points) and a p-controller without this range. In order to avoid instabilities, the time resolution of all simulations had to be set to 0.01 hour. This explains the long simulation times we experienced.

Table 1. Model details.

id	Type	Modelling solution
hf1 hf2	thermal conduction	heat transfer through wall between outdoor environment and space, based on weather file air temperature., TRNSYS wall model
hf3 hf4 hf5		heat transfer through partitions (office furniture) between space and adjacent spaces, modelled as TRNSYS walls
hf6		heat transfer through floor tiles between space and plenum
hf7	solar radiation	heat transfer through windows based on radiation data from weather file, TRNSYS window model, no shading
hf8 hf9 hf10	air exchange exchange	thermal coupling by symmetric air exchange at space air temperatures. Air flow calculated using Equation 5.
hs1	fan coil unit	feedback loop controlled ventilation air temperature and adjustable air flow, based on occupancy
hs2	misc. heat sources	heat gain from sources in the space as computers, lights, persons, based on occupancy file

6 SIMULATION RESULTS

6.1 *Experiments*

Once a simulator of the testbed is implemented and functions properly (no oscillations, iteration errors, plausible results), various experiments can be conducted to answer design, commissioning, and maintenance questions. The following parameters have been varied in over 100 experiments we have conducted so far:

- Weather files:
  a: Pittsburgh standard tmy-weather file, 365 days, resolution 1 hour
  b: constant outdoor temperatures in 5°C steps from −20°C to 40°C, 4 days each, no radiation
  c: same as b, only 1 temperature, 30 days
- Occupancy files:
  a: all spaces unoccupied all the time
  b: all spaces occupied all the time
  c: occupancy level increasing incrementally from 1 to 10, random distribution
  d: dynamic occupancy generated with the MATLAB generator (see Chapter 3.2), time resolution 0.1 h and 0.01 h.
  e: occupancy generated with the USSU generator (Tabak 2008)
- Temperature preference settings or files
  a: comfort temperature *Tp* and set-back temperature *Tsb* set equal for all office spaces
  b: individual preferred temperatures *Tp* and tolerance ranges *rt* assigned dynamically to occupancy patterns (Occupancy files 3d).
- Control algorithms
  a: comfort and set-back temperature ranges, controlled by occupancy, air temperature not controlled if in the range
  b: same as a, but zero comfort control range
- Partitioning heights (coupling factors)
  a: 0, 1, 2, 3 m, open pathway to hall spaces
  b: 3 m (ceiling height), door to hall spaces, equivalent to closed offices
- Thermal space capacitances
  a: as in real IWS
  b: load bearing steel weight reduced to zero, floor heavily insulated, furniture weight reduced.

The above listed variables allow for a large number of questions to be answered. Experiments have to be carefully planned and the results analyzed to find significant answers in reasonable times. Especially experiments with weather files 1a require more than 10 hours on an 850 MHz personal computer.

Here we will report on some typical experiments, others can be found in (Zimmermann 2008). In the following tables we denote the selection of parameter settings by a parameter vector that is composed of numbers and letters in the above list.

Figure 5 shows the outdoor temperature of the standard year in Pittsburgh, USA. It covers a large range of cold and hot weather. In addition, solar radiation adds a large thermal load. We regard this profile as a good test for the model and the simulation.

The TRNSYS model allows the introduction of more parameters such as additional thermal loads from persons and equipment, temperature changes in the plenum spaces, or humidity control. Vertical shading devices are possible, controlled by a control algorithm. These parameters have not been used in the simulations because they would complicate the interpretation of the results.

6.2 *Experiment 1: Upper and lower energy limits*

The worst case for energy consumption can be assumed when all spaces are controlled at comfort temperatures at all times. The case can occur when occupancy is spread over 24 hours 7 days a week. On the contrary the lowest possible energy consumption is reached when at all times set-back temperatures are maintained. The goal of a good control strategy is to come as close to the lower limit while maintaining individual comfort. The worst case can be improved if the comfort range is extended. Table 2 shows results of five cases.

Exp1.1 and Exp1.2 show the energy consumption of the whole IWS for a controlled 1°C temperature range

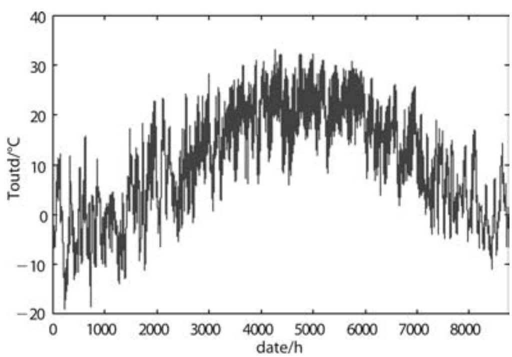

Figure 5. Pittsburgh standard weather file outdoor temperature.

Table 2. Energy consumption limits.

Exp	Parameter vector	*ET** range °C	*Energy* MWh/y
1.1	1a, 2b, 3a, 4a, 5a(2m), 6a	22–23	39.48
1.2	1a, 2a, 3a, 4a, 5a(2m), 6a	17–28	14.21
1.3	1a, 2b, 3a, 4a, 5a(2m), 6a	20–25	26.74
1.4	1a, 2a, 3a, 4a, 5a(2m), 6a	15–30	8.58
1.5	1b, 2b, 3a, 4a, 5a(2m), 6a	20–25	26.46
1.6	1b, 2a, 3a, 4a, 5a(2m), 6a	15–30	8.86

while occupied at all times and for an extended 11°C set-back range while never occupied. Both energy values are much higher than in the case of Exp1.3 and Exp1.4 with ranges extended by 4°C. Naturally ventilated buildings show that occupants can be satisfied at such large ranges. In practice the large range results in temperatures near the lower limit during the cold season and the upper limit during the hot season and varies during the swing seasons (spring and autumn).

Exp1.5 and Exp1.6 exhibit similar energy figures for the same ranges, but with the much simpler weather file 1b. Considerable simulation time can be saved with the disadvantage that no solar radiation is considered.

6.3 *Experiment 2: Occupancy levels*

One of the approaches to save energy is the control of comfort temperatures according to occupancy. It is clear that in an open-plan office this is only possible to some extent. In Table 3 we show the results for two constant outdoor temperatures and for 2 m partitioning heights only to give an impression. Because of the strong thermal coupling between adjacent spaces the results also depend on the distribution of occupied and unoccupied spaces.

Table 3 clearly shows that energy saving are significant when the occupancy level is below 60% in the case of the IWS. Such levels have been measured by Mohammadi 2007 and can be assumed to be typical for many organizations with flextime. Other experiments show that savings increase with increasing partitioning heights as is to be expected. Experiment 3 analyzes this in more detail.

6.4 *Experiment 3: Partitioning heights*

In open-plan offices partitioning walls or furniture are mainly used as optical or acoustical separation of workplaces. In the context of individual comfort temperature settings partitioning walls are a means for reducing thermal coupling of adjacent spaces. As explained in Chapter 5.2 the coupling mainly results from air exchanges through the openings above the partitions. Experiment 3 analyses the possible temperature differences between occupied and unoccupied offices as a means to save energy, but also to show the limit of maintaining different comfort temperatures in adjacent offices resulting from different preferred temperatures without heating one and cooling the other at the same time. In Experiment 4 we show that with doing the latter all temperature differences are possible, but with the disadvantage of higher energy consumption. Table 4 shows some results for the extreme cases of one occupied space between the unoccupied rest (occ1) and one unoccupied space between the occupied rest (occ9). *hp* denotes the height of the partitions.

The values in Table 4 show that in adjacent offices no large temperature differences can be maintained if energy conservation has priority. The possible differences increase with increasing partitioning height *hp* as is to be expected. 3 m partitions come very close to individual offices, but can no longer be regarded as open-plan offices. $hp = 2$ m seems to be a good compromise.

Table 3. Energy consumption as a function of occupancy level, *Tp* range: 20–25°C, *Tsb* range: 15–30°C.

Exp	Parameter vector	*Occupancy level*	*Energy*/MWh/year *Toutd* −10°C	+40°C
2.1	1c, 2c, 3a, 4a, 5a(2m), 6a	10	52.14	31.06
2.2	1c, 2c, 3a, 4a, 5a(2m), 6a	9	51.05	30.33
2.3	1c, 2c, 3a, 4a, 5a(2m), 6a	8	48.69	28.53
2.4	1c, 2c, 3a, 4a, 5a(2m), 6a	7	48.22	28.18
2.5	1c, 2c, 3a, 4a, 5a(2m), 6a	6	45.65	27.08
2.6	1c, 2c, 3a, 4a, 5a(2m), 6a	5	41.63	24.60
2.7	1c, 2c, 3a, 4a, 5a(2m), 6a	4	39.29	23.26
2.8	1c, 2c, 3a, 4a, 5a(2m), 6a	3	37.33	21.63
2.9	1c, 2c, 3a, 4a, 5a(2m), 6a	2	31.32	17.03
2.10	1c, 2c, 3a, 4a, 5a(2m), 6a	1	24.41	7.53

6.5 *Experiment 4: Satisfaction study*

In Experiment 4 we introduce the individually preferred temperatures *Tp* in a range of 20–25°C with a distribution close to Figure 2 in the ok category. The exceptions are Exp4.2 and Exp4.3 with $Tp = 22.5$°C for all spaces. All tolerance ranges *rt* are set to 1°C. To achieve high satisfaction levels, heating and cooling of adjacent offices at the same time is permitted. The parameter vector is: (1a, 2d, 3b, 4b, 5a, 6a + b).

This table needs a detailed interpretation. In Exp4.1 to Exp4.3 the thermal capacitance is as high as in the real IWS. In the last three cases it has been reduced in the assumption that a lower capacitance is better for the satisfaction because of shorter reaction times. We also assumed that the energy consumption would be reduced because of shorter return times to set-back temperatures.

Table 4. Possible temperature differences in °C between adjacent offices without heating and cooling in parallel.

hp	0 m		1 m		2 m		3 m	
Toutd	occ1	occ9	occ1	occ9	occ1	occ9	occ1	occ9
−10°C	2.21	0.80	2.77	1.12	3.55	1.80	4.76	3.31
5°C	0.90	0.34	1.11	0.45	1.54	0.70	2.26	1.19
40°C	1.56	0.75	2.00	0.84	2.82	1.37	4.31	2.41

Table 5. Energy consumption and satisfaction results.

Exp	Therm cap.	hp m	Energy MWh/y	Eheat MWh/y	Ecool MWh/y	satA	satT %
4.1	6a	2	29.70	9.08	20.62	0.83	97
4.2	6a	2	28.04	7.77	20.27	0.37	49
4.3	6a	2	28.04	7.77	20.27	0.87	98
4.4	6b	0	40.16	13.82	26.34	0.70	89
4.5	6b	2	34.84	11.18	23.66	0.80	95
4.6	6b	3	32.96	10.20	22.76	0.85	98

Exp4.1 shows a total energy consumption of 29.7 MWh/y . Compared to the worst-case 39.5 MWh/y in Exp1.1 this is a considerable saving due to occupancy controlled temperature settings. The total energy is the sum of energy consumption for heating (*Eheat*) and cooling (*Ecool*). Due to the strong solar radiation component and the assumption of no shading devices the cooling component is much higher than the heating energy. This shows the importance of shading, as it is implemented in the IWS but not modeled here. Both satisfaction metrics, *satA* and *satT* show very high values.

In Exp4.2 and Exp4.3 we have changed the preferred temperature *Tp* for all occupants to the same temperature to analyze how much the differentiation costs. The energy reduction is only 6%, but if we assume (Exp4.2) that the preferred temperatures are still in the same range as in Exp4.1, the satisfaction results are unacceptable. This supports the field study findings that in offices with a uniform temperature the satisfaction levels are low. Only under the assumption that all occupants prefer the same temperature (Exp4.3), the results would be acceptable.

Exp4.5 can be directly compared with Exp4.1, only the thermal capacitance has been reduced. The expected gain in satisfaction was not realized and the energy consumption increased considerably instead of decreasing. This is a good example how important simulations are to either prove or contradict our assumptions. The conduction of real experiments with different capacitance values would have been impossible.

Exp4.4 and 4.6 support the importance of partitioning heights. No partitions ($hp = 0$ m) require significantly more energy and result in lower satisfaction levels than 2 m partitions, as Table 4 shows.

Figures 6 and 7 explain why even during the cold season cooling is necessary to maintain different comfort temperatures in adjacent offices. Space m2 occupants request a $Tp = 23.5°$C, m3 occupants a $Tp = 20°$C. When m2 is at comfort temperature, m3 requires cooling in winter as Figure 7 shows. In contrast, space m2 (Fig. 6) requires mainly heating during the cold and cooling during the hot period, as would be expected. Some exceptions are due to solar radiation.

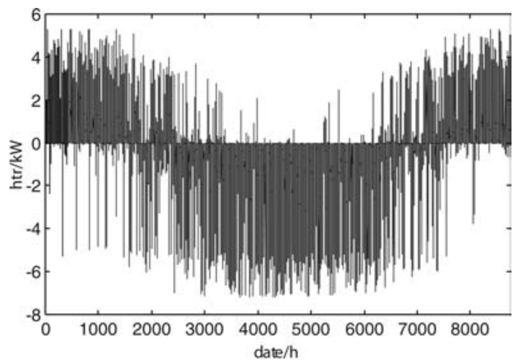

Figure 6. Heat transfer rate (htr) induced into space m3 by fan coil unit.

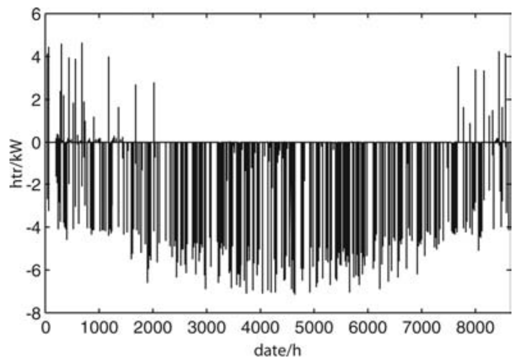

Figure 7. Heat transfer rate (htr) induced into space m2 by fan coil unit.

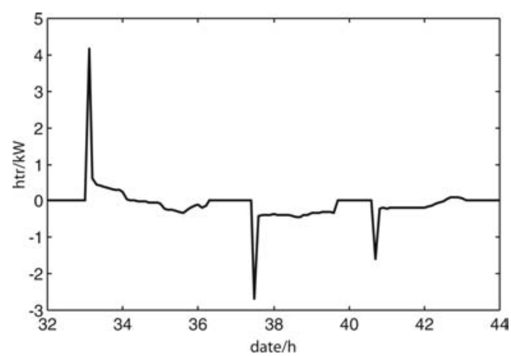

Figure 8. Detail from Figure 7.

Looking at space m2 with higher time resolution at day 2 of the year reveals a strong heat flow peak from the fan coil unit in the morning when occupancy starts and cooling peaks after short unoccupied periods. As we will see in Experiment 5, such peaks enable relatively short reaction times to temperature changes. In reality such peaks are possible if not all spaces need so

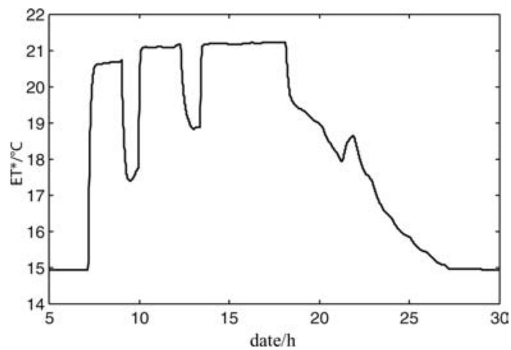

Figure 9. Temperature changes in space m2 with high thermal capacitance.

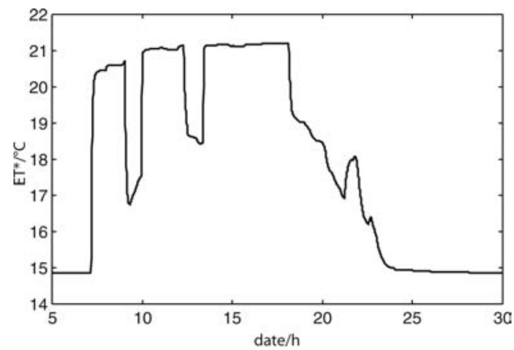

Figure 10. Temperature changes in space m2 with reduced thermal capacitance.

much power at the same time. This is one advantage of irregular work hours of individuals. For fan coil units a peak means full water and air flow for a short time. The resulting noise level has to be tolerated or longer reaction times have to be excepted.

6.6 *Experiment 5: Reaction times*

One of the problems of occupancy controlled heating and cooling is the slow reaction times of many systems. If the set-back temperatures differ largely from the comfort values, as is to be preferred to save energy, a long delay in reaching comfort values results in satisfaction problems. Therefore, it is important to analyze the time until comfort values are reached. The time to reach set-back values after occupancy has become zero is of interest for energy savings and should be short either. Both times can differ significantly because when heating or cooling is turned on, at first the air in the space changes temperature and secondly the larger thermal masses. When it is turned off, the larger masses determine the temperature change.

Experiment 5 analyzes the times required to switch from set-back to comfort temperature (*ton*) and back (*toff*) for high and low thermal capacitances in the spaces. Figure 9 shows clearly that *ton* is much shorter than *toff*. This can be explained by the control strategy. While it is important the react actively by inserting heating or cooling energy from the fan coil units when occupancy is detected, energy supply can be turned off when occupancy ends, until the limits of the set-back range are reached. The two setbacks during occupancy in the order of one hour are due to all persons leaving the space for classes, meetings, or lunch. The reason for fluctuations during the *toff* time are temperature changes in adjacent offices that influence the observed space due to thermal coupling. Table 6 lists some results.

Despite the reduction of the thermal capacitance in the office spaces, *ton* and *toff* are not reduced very much. This is another case where simulation is important because common sense would expect a much larger influence. In both cases *ton* may be short enough not to cause discomfort at work start. This has to be analyzed by field studies. It may also be short enough to be able to immediately return to set-back temperatures when the space becomes unoccupied. No control strategy with delayed reactions seems necessary.

Table 6. Reaction times during the heating period.

Exp	Reached temperature difference to final value Parameter vector	ton 0.5°C min	1°C min	toff 0.5°C h	1°C h
5.1	1c(−10°C), 2d, 3b, 4b, 5a, 6a	14	10	7.3	6.3
5.2	1c(−10°C), 2d, 3b, 4b, 5a, 6b	8	5	5.0	4.5

There are some uncertainties connected with the values in Table 6. The main is the simplified model of the fan coil units as explained in Chapter 5.2. Another is the assumption that the whole air volume including thermal masses of the furniture changes temperature uniformly. This is not true and depends very much on the air flow induced by the fan coil units in the space. This has to measured in real world experiments or with very detailed cfd simulations.

There are also options for reducing the reaction times if necessary. Predictive control algorithms based on occupancy pattern history can be applied to control the set-back temperature values dynamically. The energy cost of such strategies has to be analyzed and compared with the gained satisfaction advantage.

7 CONCLUSION

The main conclusion is that a multi-space model of open-plan offices can be set-up with plausible heat transfer equations for modelling the air flow between adjacent spaces that are divided by partitions of different heights. The model also includes for each space separate space controllers that react to dynamic space occupancies and thermal preferences. Finally the model includes HVAC equipment that is controlled by the space controllers. In summary the model integrates five domains: the building fabric with its interior layout, the service equipment, the controllers with algorithms, the workplaces, and some dynamic features of the office workers.

The model could be partly implemented, with some effort, in the commercial simulation environment TRNSYS, the model of office workers was implemented in MATLAB. The experience showed that it would be more natural and convenient to implement the complete model in multi-agent technology. This is the next goal of our research. Full year simulation took in the order of 10 hours on a single 850 MHz processor. We expect the agent-based version to be faster.

Although the model has not yet been validated against real measurements, the results of simulations can be interpreted as trends. After re-analyzing published field studies about the satisfaction of office workers in open-plan offices it became clear that high satisfaction levels can only be reached if individuals can control their thermal environment. The main conclusion we can draw from the simulations is that individually preferred temperatures in partly separated spaces in open-plan offices can be realized and that high satisfaction levels are possible with reasonable energy consumption cost if dynamic occupancy–based control is realized. A prerequisite is a space-based heating and cooling system that can change the air temperature fast enough not to cause uncomfortable times of delayed temperature reactions. Fan coil units meet this requirement.

Especially in organizations with flextime or no work hour regulations as for example in university offices and labs, open-plan offices can be required to be set to comfort temperatures at all times in the worst case if micro-zones can not be controlled separately. The results show that micro-zoning with occupancy-based control can achieve significant energy savings, even when different temperatures are enforced in adjacent spaces at the cost of partial cooling during heating seasons and vice versa.

More energy can be saved when the tolerance ranges of individuals are enlarged. de Dear et al. 1997 drew the conclusion that these ranges are mainly the result of expectations, not so much of real needs. In naturally ventilated buildings the ranges are much larger than in air-conditioned ones. Many questions still have to be answered in this respect. One question is: can we use the field study data to predict preference distributions or do they only show what individuals are willing to accept in given environments? How would they react in environments they can individually control? Can dynamic feedback of the consequences of their control settings lead to wider tolerance ranges and better energy usage without decreasing satisfaction levels? More field studies in open-plan offices that are equipped accordingly will be necessary to answer these questions.

We hope that this paper will encourage other groups to conduct filed studies and real experiment that will help to answer the above questions. We also want to express our gratitude towards the Centre for Building Performance and Diagnostics (CBPD) at the CMU, Pittsburgh, USA to support and let me use the IW as a testbed for measurements and simulations and provide me with the necessary data and information. I am also grateful for the many constructive discussions with members of the CBPD.

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Using constraints to validate and check building information models

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ABSTRACT: As the IFC model has been developed and implemented, the focus has been on the development of model views against which software applications can be certified. As more implementations have been certified and as IFC usage in practice has started to grow, limitations in the view/certification procedure from the perspective of the user have emerged. Whilst a view satisfies the needs of a software vendor, it may not fully meet the needs of a user. A more detailed approach to supporting user needs is required.

There has been significant effort over the past few years in the development of the Information Delivery Manual (IDM), an initiative that seeks to break down the content of the IFC model (and potentially other standards based models) into business process driven data sets that are user oriented. These are termed 'exchange requirements'. For each exchange requirement, the IDM methodology proposes that there should be a set of business rules that can be used to check that the information captured in the exchange.

In parallel, support for the automated checking of building codes and regulations has developed through the SMARTcodes project for the International Code Council. This enables building regulations to be captured using constraint that are defined according to the IFC constraint resource model.

In this paper, recognizing the similarities between checking exchange requirements and building regulations is used to drive the objective of developing automated validation procedures to support users. A further objective of extending the approach to deal with explicit implementer agreements in support of view based certification is also recognized and described.

1 BUILDING INFORMATION MODELLING

Building Information Modelling (BIM) is the term applied to the creation and use of coordinated, consistent, computable information about a building project in design, in construction and in building operation and management. It replaces 'Computer Aided Design' (CAD) and places the emphasis on the ideas of 'information' and 'modelling'.

A 'Building Information Model' is the collection of objects that describe a building where an object represents an instance of 'things' used in building construction, that can include:

- physical components (e.g. doors, windows, pipes, valves, beams, light fittings etc.),
- spaces (including rooms, building storeys, buildings, sites and other external spaces),
- processes undertaken during design, construction and operation/maintenance,
- people and organizations involved,
- relationships that exist between objects.

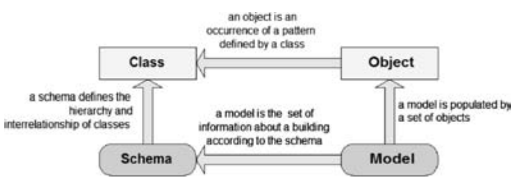

Figure 1. Elements of building information modelling software.

An object is an occurrence of a class. A 'class' provides a template for the data attributes or information that characterize an object. For instance, 'window' may be a class specifying that width, height, number of glazing panes, glass type and frame construction must be given for any occurrence of a window. The values for these data attributes are asserted for the object.

A schema identifies the classes that can be used and the relationships that exist between them. It specifies the data structures of the database supporting the BIM.

1.1 *Interoperability*

Virtually all of the surveys carried out in the building construction industry place interoperability as the key issue for the use of Information and communication technologies (ICT). This is supported by roadmapping development such as the ECTP and supporting national efforts. The evidence for available cost benefit comes from a study by the US National Institute for Standards Technology (NIST) in which US$15 billion is estimated as the cost to US industry of the lack of interoperability. This equates roughly to 1.5% of US construction turnover. However, more recent estimates suggest that this figure is too low, the true figure being closer to US$45 billion of 4.5% of turnover.

This is the equivalent of having $100 in your pocket, then taking out a $5 note and burning it! You wouldn't do it in real life. But we do it every day on construction projects.

Interoperability requires that there must be a common understanding of the building processes and of the information that is needed for and results from their execution. This is provided by the Industry Foundation Classes (IFC) information model that provides a comprehensive reference to the totality of information within the lifecycle of a constructed facility. It has been developed since 1996 as an integrated whole in response to business needs identified by the international building construction community and is now mature, powerful and stable.

The complete IFC information model is developed as a set of individual topic schemas. Each topic schema typically represents a consistent overall idea (e.g. structural analysis, HVAC, cost, materials etc.). On completion, all of the topic schemas are brought together into the single schema which is the authorized working version. Currently, this is designated as IFC 2x3. The core part of the IFC model (termed the Platform) forms the ISO/PAS 16739 standard.

IFC can store information about most aspects of a building project including:

- shape
- schedule
- cost
- client brief and requirements
- design and analysis information
- procurement and construction data
- operation and maintenance records

All of the major CAD vendors now support the IFC model. There is also an increasing number of non-CAD software applications that can use IFC data. In total, the extent of support for IFC now measures in the hundreds of applications.

1.2 *Extensibility of the IFC schema*

Since there are limitations to the level of detail used to define classes within the IFC schema, there is a need to be able to provide extended detail without changing the schema.

The major idea for extending content that can be exchanged with IFC is 'property sets'. A property set is a collections of free attributes that can be assigned to objects defined within the IFC schema (including proxies).

1.3 *Naming and language*

All terms and words used throughout the standard, published IFC schema and documentation are in English. This enables precise control of the meanings of terms and words throughout IFC (the semantics of the model).

However, extensions to the IFC model can often be freely specified according to language (British English, French, Norwegian, Japanese etc.). Whilst this is allowed within IFC, it can generate some problems if you want to want to strictly control the semantics throughout the whole of a populated IFC model. This is something that you will want to do if the aim is to use the IFC model for something more than just data exchange. For instance, if you want to apply a context such as building regulation compliance.

1.4 *Dictionary*

There is an ongoing effort to control the free use of terminology through the provision of an online dictionary. This is through the "International Framework for Dictionaries" initiative which is based on the development of the ISO 12006-3:2007 standard and which now includes membership from Norway, Netherlands, United States and Canada.

There are several key aspects to the IFD dictionary that make it very useful in the idea of capturing and using knowledge from BIM. These include:

- the ability to store multiple classification system within its structure without itself being a classification system.
- the ability to hold several ontologies in it structure without itself being an ontology.
- the ability to supplement IFC by providing the semantic control that it needs particularly in regard to the property set extensions and to the application of constraints.

2 INFORMATION DELIVERY MANUAL

The purpose of the Information Delivery Manual (IDM) is to define the information that one AEC/FM industry user needs to provide to one (or more) other AEC/FM industry users to support their work. This means that IDM delivers information at specific points in the business process.

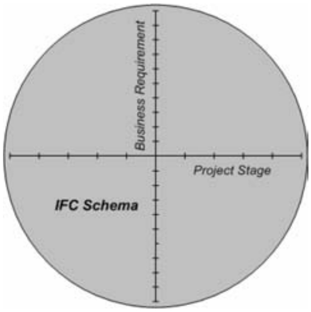

Figure 2. Supporting all requirements at all stages.

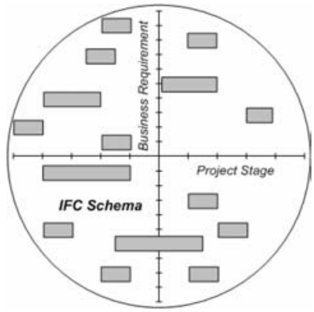

Figure 3. Supporting a requirement at one stage.

As well as defining the information that is needed, IDM also includes the idea of a 'Manual'. That is, it gives guidance to users on providing the information both at a general level and specifically for individual software applications.

2.1 *Why is it being developed*

The development of standard information specifications (such as IFC) for the AEC/FM industry has been done at a high level basis. That is, the aim is to capture all of the information for all business requirements for the whole building lifecycle and for all building project participants.

It is more usual for information to be exchanged about one (or a limited number of) business process at a time and at a level of detail set by the project stage. This is the approach supported by solution providers and required by software users.

For this purpose, a standard project lifecycle model has to be broken down into a series of parts where each part meets the exchange requirements driven by the business process. That is, each part describes the message passing from one business process to enable another business process. IDM provides this breakdown whilst retaining all of the capabilities of the complete project lifecycle model.

2.2 *What are the IDM components*

IDM includes a set of components that move progressively from describing business processes to being able to control how information is exchanged for a particular purpose.

A reference process is type of activity that has a universally consistent definition both in terms of its meaning and its attributes/properties. A reference process may have many process occurrences within a building construction project. Occurrences are configured into process maps.

A process map describes the flow of activities within the boundary of a business process. As well as the activities, it shows the sequence in which they take place. The various people and organizations who are actors in the process are shown and the messages passing between these actors as a result of activities being done is shown. The messages are termed 'exchange requirements' since they define the information that needs to be exchanged as a result of one activity occurring to enable another activity to start. See fig XX for a more detailed example process map.

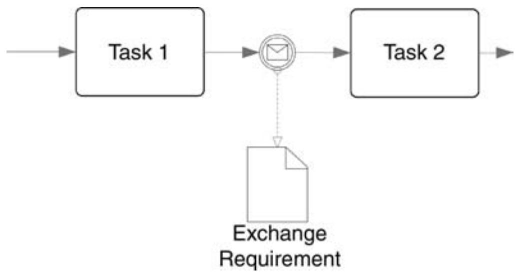

Figure 4. Exchange requirement message.

An exchange requirement is a set of information that needs to be exchanged to support a particular business requirement at a particular stage of a project. It is intended to provide a description of the information in non technical terms.

An exchange requirement represents the connection between process and data. It applies the relevant information defined within an information model to fulfil the requirements of an information exchange between two business processes (tasks) at a particular stage of the project.

A functional part is a unit of information that supports an exchange requirement. It describes the information in terms of the industry standard information model upon which it is based. Although a subset of a standard, a functional part is itself a complete information model.

A functional part is concerned with a particular unit of information within an exchange requirement such as modelling walls, windows, doors, slab, roof etc.

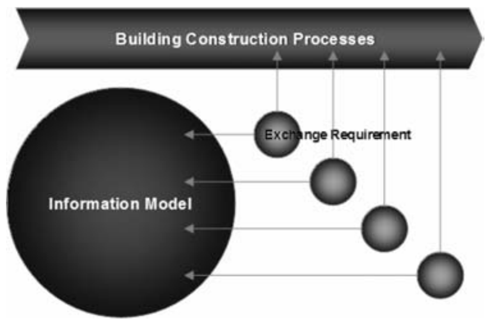

Figure 5. The intersection of process and data.

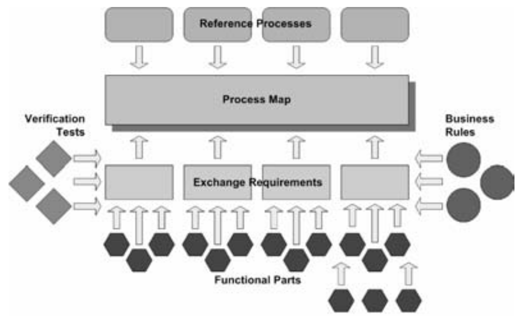

Figure 6. The IDM technical architecture.

It contains a detailed technical specification of the information that should be exchanged including every entity and every property within the standard information model used (e.g. IFC, CityGML). A functional part may call on the services of other functional parts.

A business rule provides a way to control the use of specific entities; the properties that must be used (or that must not be used); the values that a property may have; and the dependencies between entities or properties or property values.

Business rules can be used to vary the result of using an exchange requirement without having to change it. This provides exchange requirements with agility so that, through the application of different sets of business rules, different local usages can be defined.

IDM also allows for the development of examples and test cases that are valuable in verification testing for the accuracy of IDM usage. It also encourages the provision of implementation guidance for solution providers (through functional parts) and user guidance for specific software applications (through exchange requirements) so that end users have instruction on how to configure their systems for IDM use.

2.3 *How do they link up*

The various IDM components are linked together by a 'technical architecture' that is designed to provide a structured connection between all levels of the IDM approach. This is shown in the technical architecture diagram below and may also be described by:

– A process map describes one or more points of information exchange, each point being identified as an exchange requirement.
– An exchange requirement contains one or more functional parts.
– An exchange requirement is technically described by the functional parts it contains; this means that an exchange requirement may contain other exchange requirements.
– A functional part may contain zero, one or more other functional parts.
– An exchange requirement may be acted upon by zero, one or more business rules.

Note that the business rules actually act upon the functional part used in the scope of the exchange requirement.

3 THE BUILDINGSMART REQUIREMENT

The idea that automated code checking is possible has long existed in Singapore. First attempts to achieve this were made using early artificial intelligence methods. However, the technology was not sufficiently mature and the effort was abandoned. In the late 1990's the BP Expert was developed. This enabled the automatic checking of disabled access to buildings based on 2D computer aided drafting (CAD) data. BP Expert needed specially developed software running on a particular CAD system and a specific file format. It needed costly maintenance every time a new version of the CAD system was released. Thus, whilst BP Expert showed the potential for automated checking, it was not a long term solution.

These early experiences led to the conclusion that a long term solution could only be achieved by using 'commercial off the shelf' software with rich data handling capabilities and a neutral file format supported by multiple software applications.

The first part of this problem was resolved by the various CAD vendors moving to Building Information Modelling technology. The second part was found though the IFC data model.

The IFC model was found to be sufficiently rich in it's ability to handle data (particularly after it was extended specifically for the purpose) to support the necessary content for building codes within a building information model AND to support the development of a set of IFC enabled rules that could be used to test the compliance of a submitted model.

3.1 *Interpreting building codes as rules*

Work on the Singapore ePlanchecking system comprised three key components:

– Extension of the IFC model to include important concepts needing to be checked for compliance.
– Interpreting the building codes to ensure that their requirements could be supported by the IFC model or to provide the requirements generating extension of the IFC model.
– Coding the rules into the rule schema of the Model Server software (Express Data Manager or EDM).

The process of interpreting the codes was carried out in three stages:

– dealing with building code clauses that could be checked using the IFC model without any extension or change being made;
– dealing with clauses that could be checked using property set extensions to the IFC model;
– dealing with clauses that could only be dealt with by adding to and making changes to the IFC model.

For each stage in the process, interpretation required the actions:

– propose one or more rules for each clause based on assessment of its provision.
– meet with a building code official to test that the proposals are acceptable to the code official (proposed rules deal with the clause exactly as the code official would).
– amend the proposed rules and continue to test them with the building code officials until agreement is reached.

This set of actions can take a significant amount of time.

4 SMART BUILDING CODES

4.1 *The We4C Vision*

We4C, which means 'Working electronically For Construction', was the name given to a set of 'brainstorming' meetings held in 2004/2005 between European Research groups active in the areas of applying reasoning to decision making in the building construction industry. The aim was to consider ways of presenting regulations in a logical way that enabled them to be applied in an appropriate context and in the relevant language according to location.

Several ideas resulted significant amongst which was the development of a vision for building code checking that would allow the use of mark up tags from a 'tag dictionary' (or ontology) and which would then enable the automatic extraction of compliance checking rules. The key idea here is that the rules would follow a strict mathematical pattern that could be defined within an external rule schema.

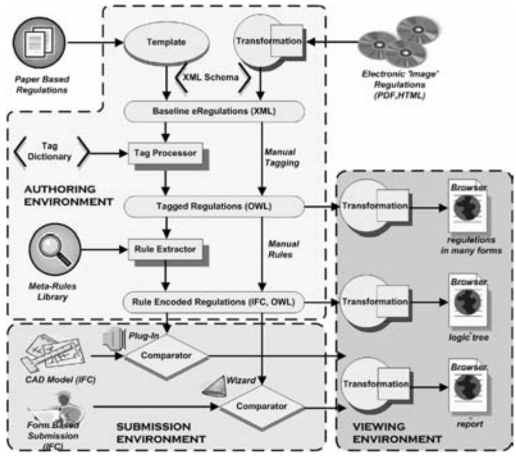

Figure 7. The We4C vision for building code checking.

The realization that this vision could be achieved gave the impetus to make automated code checking a reality in the US and make codes 'smart' (e.g. SMARTcodes). Much of the work mentioned above provided a valuable foundation with which to proceed with this activity in the US.

4.2 *Automated building codes in the United States*

The purpose of a building code is to establish minimum requirements necessary to protect public health, safety and welfare in the built environment. The International Code Council (ICC), a US based membership association dedicated to building safety and fire prevention, develops codes for use within the US and elsewhere to construct residential and commercial buildings. Most U.S. cities, counties and states have elected to base their requirements on ICC codes.

ICC Codes are model codes. Legislative bodies do not have to use model building safety or fire prevention codes, and may write their own code or portions of a code. However, many jurisdictions use model codes because they keep construction costs down by establishing uniformity in the construction industry. Federal, state and local agencies also make amendments to the codes and these typically include modifications and additional criteria to meet local requirements. A model code has no legal standing until it is adopted as law by a competent legislative body (federal agency, state legislature, county board, city council, etc.) and each state has its own legislative and enforcement structure. When adopted as law, all owners of property within the boundaries of the adopting jurisdiction are required to comply with the referred codes. Currently, the International Codes are adopted at either the state or local level in all 50 states and by many federal agencies.

In 2004, ICC determined that it needed to look at using object based technology for representing their codes and for testing submissions against them. Having researched the topic and looked at developments in Singapore, Norway and elsewhere, the Board of Directors of ICC comprised of building regulatory leaders from state and local agencies approved investment in and leadership of a project in late 2005 to make automated code checking a reality in the US. This project, solely funded by ICC, has been underway since January 2006 and among other activities under the project is creating SMARTcodesTM for the International Codes.

4.3 *Interpretation using SMARTcodes*

The SMARTcodes project uses lessons learned in previous code checking development projects and from improvements in technology. In doing so, it represents a further step in the development of automated code checking in building construction. For the first time in such a project, it is working directly with the building codes themselves as well as with the automated checking of submissions against the codes.

In previous projects, the key obstacle has been the interpretation and presentation of the building codes and the encoding of that presentation in a rule base. Presentation has been difficult because of the need to ensure that the result was the same as if checking had been done by the human expert and this involved extensive consultation with building regulatory officials. Developing the rule base was an issue because of the need to encode the rules by hand within a single rule checking system (although the rules themselves were encoded in the ISO standard EXPRESS-X language).

Both of these situations and past obstacles have been addressed within the SMARTcodes project.

4.4 *Code structure*

When work commenced, the ICC codes were already electronically available in a form of XML. This provided a significant platform for the next stage of the work.

The We4c activity had proposed that it should be possible to mark up regulations in such a way that rules could be automatically generated. Research showed that work on text processing was making significant progress in the legal sector so that transcripts and other court documents could be searched based on knowledge criteria. By examining this research, an approach was determined that could achieve a similar result with building codes. This was tested and proved to work and in the project is referred to as the protocol for creating SMARTcodes.

The major breakthrough then occurred with the development of a simple Windows-based approach that enabled ICC staff and building code officials familiar with the codes to take the ICC codes or unique amendments or additions to the codes and, with the protocol guiding them, create SMARTcodes. This is done using the electronic equivalent of a ‘highlighting pen’ with different colours used for each concept in the mark-up and is referred to as the SMARTcode builder software. The number of colours is not a major issue as there are a surprisingly limited number of concepts within a building code. Tests with this approach have shown that code officials understand the approach very quickly and do not make mark-up errors. This resolves the issue of presentation of the codes in a ‘smart’ format and the massive effort it would otherwise require. It also enhances the uniformity in creating SMARTcodes, thereby allowing for multiple people to work concurrently on creating SMARTcodes for all the ICC Codes. The speed and effectiveness of ICC mark-up is expected to be much higher than was previously the case and the cost significantly less.

To simplify presentation further, the SMARTcode builder mentioned above that is essentially a customised XML editor only allows mark-up according to the SMARTcodes schema. This tool is a very easy to learn and use and gets over the fact that tools like XML Spy, whilst perfectly capable of doing the task, have so many features that they can become confusing to use. The question of colour blindness by users is also dealt with through the use of web accessibility guidelines.

4.5 *Dictionary support*

Although the number of mark-up tags used by SMARTcodes is currently limited, the number of properties that are within the codes and that need to be tested and that have to be encoded as attributes of the tags is very large. The same property can occur within the codes in many places and it is important that it is always assigned the same meaning and unit of measurement.

To assist this, a dictionary of the properties found within the building codes is being developed. The dictionary is being developed as part of the International Framework for Dictionaries effort and, in the US, is being managed by the Construction Specifications Institute (CSI) in cooperation with ICC. This work is also enabling the properties within the codes to be identified against appropriate tables within the Omniclass classification system that has been developed by CSI.

An added advantage of the dictionary and classification based aspect of the work is that it enables the codes to be searched to determine only those that are relevant to a particular topic and to deliver these exclusive of all the other, non-relevant codes. This can reduce the total set of building codes that have to be consulted for a project not only in the automated code checking application but the manual code searching capability that is being created by ICC to allow those without a BIM to interact with SMARTcodes to secure and apply project-relevant code criteria and related support materials such as reference standards, code commentary, interpretations and manufacturers data on building products and systems.

4.6 *The requirements model*

Having presented the building codes in 'smart' format, the second breakthrough of the SMARTcodes project is that, through the execution of a automatic process, the actual rules against which submissions will be checked can be automatically generated directly from the code mark-up. In fact, what results is a 'requirements model' that is captured in the form of a series of constraints encoded according to the IFC constraint mode. This is a standardized representation of the rules. This makes it completely independent of any rule checking software and allows for a 'plug and play' scenario for any codes, standards or regulations that are put in this 'smart' format.

The approach has been tested with multiple software applications that have been adapted to use the IFC constraint based requirements model as a rule base.

4.7 *Comparing solution and requirements*

The vision behind the SMARTcodes project is that IFC based submissions from architects, engineers, contractors or others that are regulated should be able to be automatically checked for code compliance using computer systems before submission to building regulatory authorities. Within the terminology of the SMARTcodes development, an IFC file representing the building model is considered to be a 'solutions model'. The intent is to test it against the 'requirements model' or SMARTcodes and identify any conflicts or areas where the building model does not contain the information necessary to assess compliance.

SMARTcodes is probably the first development for the AEC/FM industry to use this idea of twin models with a standardized schema. However, the idea is not unique or new. Kiviniemi, suggested that multiple models will be needed to handle the various issues that will arise in practical use of building information models. In fact, even as far back as 1986, Gielingh was advocating different models for use at different project stages through the concept of 'product definition units' (PDU's) where each PDU represented the model of the building at different stages of development.

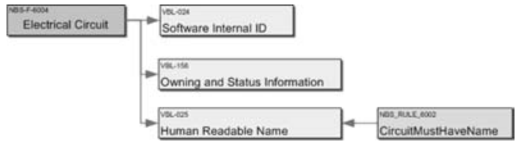

Figure 8. Applying a rule to an electrical circuit.

NBS_RULE_6003	IEC_CircuitType	The object type of an electrical circuit must be selected from the legal circuit types defined within IEC 60364	IfcElectricalCircuit.ObjectType = 'TN' or 'TN C' or 'TN S' or 'TN C S' or 'TT' or 'IT'

Figure 9. Identification of an IDM business rule.

The derived 'requirements model' is expressed as an extensive logical tree, with the overall regulation at the root, and specific testable metrics as the leaves. The evaluation of each leaf metric is governed by the dictionary, and may return 'true', 'false' or 'unknown'. Different model checking applications can explore the branches of the tree with different heuristics depending on the user's priorities, and the efficiency of the individual tests.

4.8 *Using requirements for validation*

If we assume a building code to represent a requirement a constraint that can be applied to a BIM, we can look to see if there are other such constraints that can be applied. Once we start to look, we find that there are many. Any specification is a constraint as also is any performance requirement. Condition based maintenance relies on constraints as does all forms of automatic control. Most importantly, for current consideration, a contract is a set of constraints.

From this viewpoint, we can consider the idea of contractually significant data exchange. This is a data exchange with a known content and that can be validated in the context of its use. We find that exactly the same approach as can be used in building regulations checking can be applied to data exchange validation. In fig. 8. we see a rule applied to an electrical circuit that it must have a human readable name. We might also require it to be designated as a circuit type where the type designation is taken from those allowed by an IEC standard.

Increasingly, the use of rules is able to impact on how software implementers test and certify software. As part of the buildingSMART certification process, implementers agreements are made to deal with situations where the IFC model does not completely deal with requirements or where ambiguity exists in the model. Within the coordination view of the IFC model, it is being found that many of these agreements can be represented as rules and therefore tested

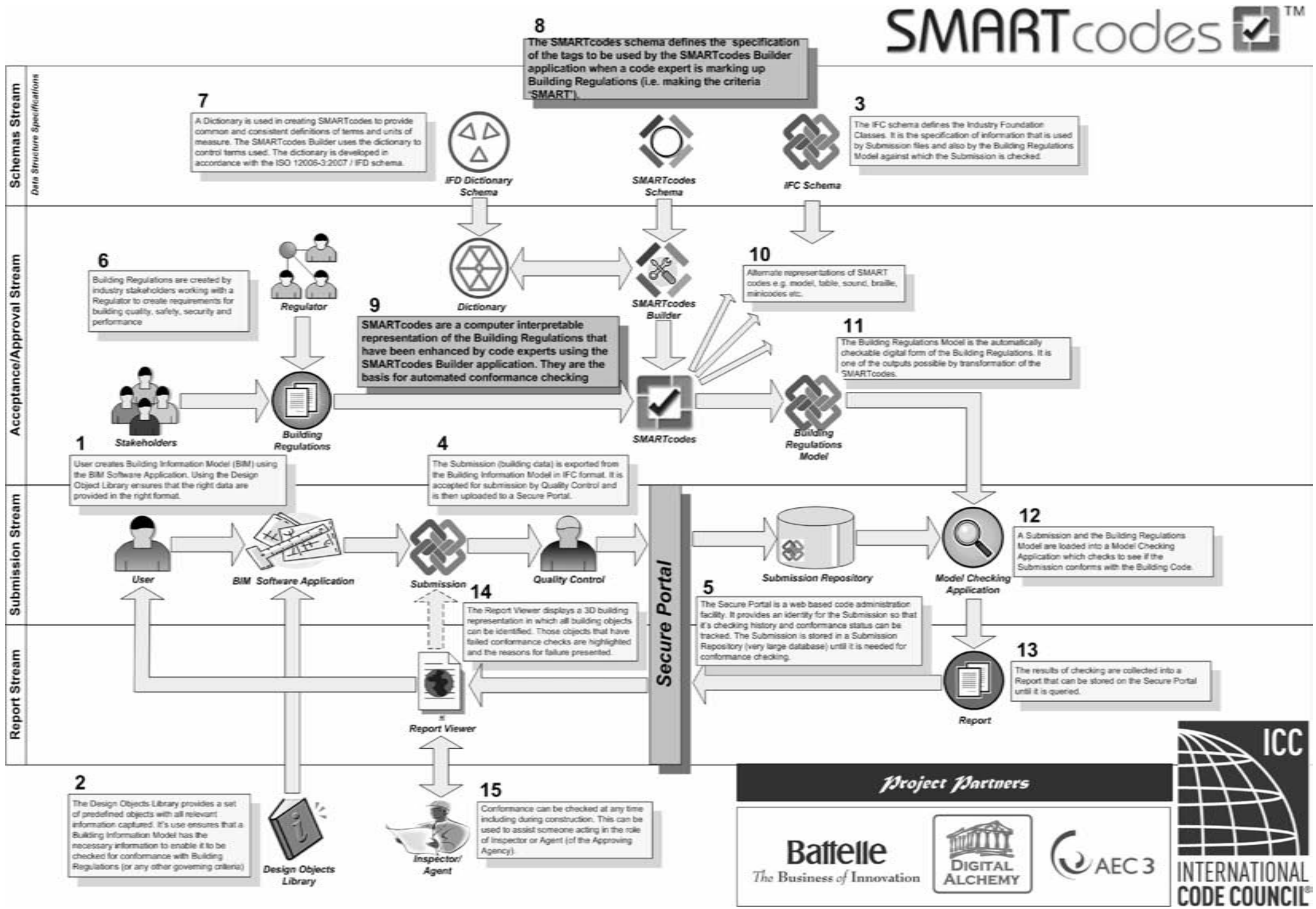

Figure 10. Overall architecture of the SMARTcodes project.

more automatically. As the number of views on the IFC model grows, and this is already happening, the need for more automatic and accurate testing will also grow. The manual means of testing that have been applied to certifying applications for the IFC coordination view will not have the capacity to meet the demands that will be made. IDM based rule checking is the approach that will need to grow to meet the demand.

4.9 *Reporting the results*

The reporting of the results must be tailored to the needs of the user: a designer requires a clear indication of what and where in the building the area of non-compliance occurs, with an indication of the metric that proved critical, whereas a code compliance official requires a clear formal statement of the failure, properly referenced to the original code. Both require a reasoned explanation based on the values and targets found in the critical metrics. The reasoning is then related back to the specific code requirement.

Some code requirements are explicitly unknowable in the design context. One common example is when the requirement anticipates inspections on site during the construction phase. In this case the results would be reported as not capable of being assessed until the construction phase and the results formatted to notate this and what is to be confirmed later. Some code requirements use the term "acceptable to the authority", which can only be ascertained through direct contact with the applicable authority. In this case the results would notate this as indeterminate and direct the designer to discuss with the authority.

5 CONCLUSIONS

SMARTcodes embeds mark-up tags in the regulations to enable two distinct endeavours. The first is the extraction and exploration of the essential logical structure of the regulation. The second is the extraction and development of a growing catalogue of testable concepts that can be defined and evaluated. By separating the two, code compliance checking across multiple jurisdictions is being made a practical reality.

Gaining code compliance approval is a major milestone during the progression of building construction projects, but is often the largest single delay between inception and handover. It represents a hiatus during which momentum and knowledge is dissipated. It is a particularly significant example of the need for contractually binding information exchanges. By reducing the cost, delay and risk associated with both major and minor design review points, systematic and automated checking can support progressive design improvement and better collaboration. The more critical the exchange the more well-defined it must be: a failed exchange wastes time and effort for both the sender and receiver. The IDM methodology delivers the definition of the information that must be exchanged during the design processes. It directly supports the generation of IFC constraint models alongside those from the schema, implementation agreements, and view definitions. These constraint models can then be used to validate the information in the exchange, independent of whether the receiver is about to apply an interactive design tools or a rule-based checking procedures.

With the exchanges controlled and rule-based checking automated, the construction industry can focus on the proper value-adding processes within project design and delivery.

ACKNOWLEDGEMENTS

SMARTcodes is a registered name and trade mark of the International Code Council Inc. 500 New Jersey Ave. NW, 6th FloorWashington D.C. 2001, USA.

A 'test drive' of SMARTcodes and their operation in conjunction with the Solibri and Xabio software applications is available at www.smartcodes.org . This allows several different test buildings to be checked for energy code compliance in multiple geographic locations.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

On line services to monitor the HQE® construction operations

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ABSTRACT: In order to promote and foster the environmental quality of new building at early phase of design, several tools and methods has been tuned during the last few years. The HQE® approach is the French reference, with the standard NF certification for Buildings in the Tertiary Sector. In addition to these formal protocols, a software tools was design to serve as a shared on line information platform, dedicated to the monitoring and follow-up of building project during the design and definition phase. This tool was carried out by CSTB – ICT department in close collaboration with the CertiVéA company.

1 OVERALL PRINCIPLE AND CONTEXT

1.1 *Toward a new generation of buildings in the tertiary sector*

Environmental issues are taking an increase part in building's owners project for future construction (CSTB 443, 2003). Among multiples motivations among for improving quality, main objectives are to reduce overall cost and environmental impact during the construction phases, as well as to better master the global performance and comfort in use, while reducing energy consumption (Flesselle 2003). The tertiary sector includes all offices in general, and represents a major stake in environmental quality, because of the continuous growth of this market. Along with this market growth, the need for appropriate tools is introduced in this paper and a software solution is described.

1.2 *The environmental quality assessment*

The HQE® approach was designed to ensure the environmental quality of building. Since 2005, the NF mark for Buildings in the Tertiary Sector using the HQE® approach is fully operational in respect of office blocks and educational buildings. At first the evaluations were conducted by CSTB at key points in each operation at the end of program, design and implementation phases. The evaluations include auditing the Operational Management System (OMS) and verifying the Environmental Quality of the Building. It gives an entitlement to use the NF mark on Buildings in the Tertiary Sector using the HQE® approach, providing evidence of compliance with the HQE approach and its aim of ensuring that buildings are comfortable, healthy and respectful of the environment.

2 MANAGING NF MARK FOR BUILDINGS IN THE TERTIARY SECTOR

2.1 *CERTIVEA to run NF marks*

CertiVéA was settled in May 2006 as a private owned company, subsidiary of CSTB, to manage the certification of players in the construction industry and building structures. The aim of this transfer was to distinguish the business of certification of players in the construction industry and building structures from the other activities of CSTB. CertiVéA now assists construction activity in its undertakings to improve performance, in particular concerning the environmental quality of buildings (NF certification for Buildings in the Tertiary Sector using the HQE® approach), the operational procedures of architects (MPRO Architect), promoters-builders (QUALIPROM) and leasing contracting authorities (QUALIMO).

2.2 *NF mark for buildings in the tertiary sector*

Recent years were marked by growing interest from the public and from players in the construction industry in environmental quality (Peuportier 2003) and, in particular, the NF mark for Buildings in the tertiary Sector using the HQE® approach, launched in 2005. The increase in the number of certified operations (19 at the end of 2005, 55 at the end of 2006, more than 100th in 2007) bears witness to this, as do the agreements signed with Generali and three mixed economy companies, Seine-Arche, Val-de-Seine and SEMAPA.

A new updated version of the technical certification reference system was issued in September 2006 to take into account the latest changes in the thermal regulations of 2005, and modifications to the acoustic section to include the benefit of experience. The extension of NF certification for Buildings in the

Tertiary Sector using the HQE® approach to other tertiary sector buildings is planned by CertiVéA.

2.3 *The Operational Management System*

The Operational Management System (SMO) is a global working method, to monitor buildings applying for the NF mark for Buildings in the Tertiary Sector using the HQE® approach. It was design to prioritize targets, to set the relevant environmental objectives, to organize the operations in order to achieve them, and to evaluate the Environmental Quality of Buildings (QEB) at key moments in the operations. Office and teaching buildings in the field currently covered by the reference system may thus benefit from the NF mark for Buildings in the Tertiary Sector using the HQE® approach.

2.4 *From a printed method to an on-line service*

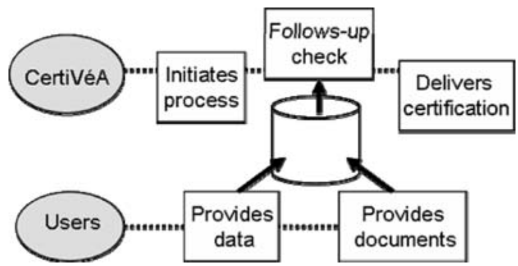
Regarding the increasing demand for HQE® Approach in the tertiary sector, CertiVéA had to decide on suitable tools to support its business and widen the market. There was a need for supporting tool to improve the certification process, especially in the following (two) directions:

- At the educational level, to facilitate the understanding of the HQE approach certification by construction operation managers. As a strong commitment is needed all along the certification process, the building owners should be fully convinced of their overall interest when applying for the NF mark for Buildings in the Tertiary Sector. The reference frame of HQE® certification for buildings in the tertiary sector includes 14 HQE targets, spited in many sub-targets and even more topics. Therefore, the full process required essential knowledge about the overall principle and method to properly run the SMO (Operational management System).
- At the operational level, to help both sides (CertiVéA and customer) to go through the incremental process of the HQE® approach, and to ensure accurate compliance with NF certification reference frame. Several steps are compulsory for final evaluation: program (deciding a construction project), design (shaping the building) and implementation (building) phases. This requires a close follow-up of each phases with relevant information to be produced by both CertiVéA and the construction management.

The specific tools designed and developed to monitor the process, collect information, and produce final documents, will be described later in this paper.

2.5 *Overall principle and specification*

The HQE® approach software tools had to meet very high levels requirements, to fully answer the double users' needs. On one side CertiVéA was willing to manage the tool, running the administrative part and checking further continuous use by the construction owner. On the other side, the construction owner, in charge of the HQE® approach for the building project under his responsibility, is allowed to use and guided all along the process, and allowed to type in relevant information when required. The HQE® approach software acts as a shared platform to support the technical exchanges between the certification body (CertiVéA) and a building players applying for the Building NF mark.



The major steps are the following:

- After agreement with the customer on the HQE® approach follow-up, CertiVéA initiates the platform and open controlled access to the customer.
- Project responsible at the user's side can then describes the environmental feature of his building project, with respect to each target and sub-targets. He can either input data or types-in additional information, and attached documents when required.
- At any times CertiVéA officer can check and review the work under progress, and contact the users for any remarks or questions. The full process of filling all information for a project can be several weeks long, as a large part of the data are not yet stabilized at the beginning of the program phase.
- At the end of each phase, the process is temporarily locked, and an intermediary evaluation is performed by the follow-up officer from CertiVéA. The analysis is based on the information provided by the customer and gathered in the platform.
- When completed, the platform gathers all the relevant information and document, for CertiVéa to draw out conclusion on the NF mark. A final report can be edited and decision about NF mark attribution can be taken.

3 TECHNICAL CERTIFICATION REFERENCE OF ENVIRONMENTAL QUALITY OF BUILDING (QEB)

3.1 *QEB profile (Certivea, 2005) (Certivea, 2006)*

Environmental quality of a building is represented by 14 targets, each target dealing with an environmental issue for an operation of Construction or Reconstruction. These 14 targets are subdivided into sub targets which are at least subdivided into elementary preoccupations. Possible performances associated with targets are:

- Basic,
- Competitive (P)
- Very Competitive (TP).

Environmental and sanitary performances are summarized by the QEB profile witch associate aimed performances with each target and related sub targets.

To pass the HQE certificate HQE profile has to meet the following requirements:

- 3 targets minimum Very Competitive (TP)
- 4 targets minimum Competitive (P)
- 7 targets maximum Basic (B)
- The target 4 has to be Competitive or Very Competitive.

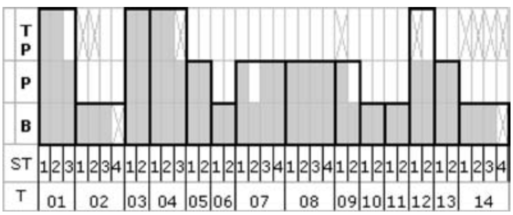


Figure 1. Instance of fictive QEB profile.

This profile is defined accordingly with the context of the operation and needs explanation to be provided by the building's owner. HQE profile can change during the operation but these changes must be reported and justified by building's owner. A profile is defined for each phase to take into account these changes of project parameters.

3.2 *QEB assessment*

QEB assessment process allows checking that QEB profile is reached for the different construction phases. A phase may get as QEB assessments as building owner needs, if at the end of assessment building owner realize that HQE profile is too optimistic, he can redefine a new one. To make this check it needed to compare project characteristics with QEB demands applicable to the aimed profile. Also, the assessment has to be based on quantitative justifying elements like dimension calculation, metric report…and qualitative elements as graphical elements, studies, reports…

3.2.1 *QEB assessment method*

QEB assessment is made on an ascendant way in a tree structure containing targets, sub targets and preoccupations:

- Preoccupations performance is given by assessment criteria

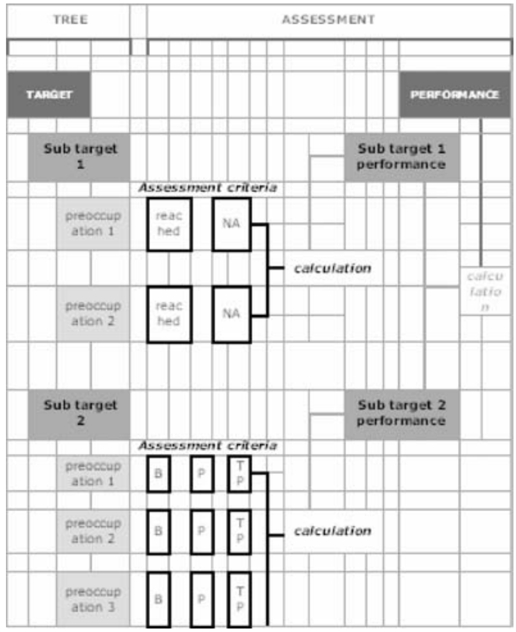


Figure 2. Assessment method.

- Sub targets assessment result of calculation according to preoccupations performances
- Target assessment resulting of calculation of sub targets performances.

3.2.2 *Preoccupation assessment*

Each preoccupation is represented by one or few characteristic(s). There are two ways of assessment:

- *CASE 1*: Via the assessment criterion value associated to the characteristic, preoccupation is so qualified thank to a performance level B, P or TP
- *CASE 2*: Via the assessment criterion state, in this case preoccupation is qualified by level Reached (R) or Not Reached (NR)

Preoccupation	Characteristic	Criteria	level
5.2.1. Gestion de la rétention	Débit de fuite après réalisation	Inférieur ou égal au débit de fuite initial	B
		Inférieur ou égal au débit de fuite initial Et Inférieur au débit de fuite correspondant à une imperméabilisation de 30% de la surface de la parcelle	TP

Figure 3. Instance of preoccupation with associated level.

Preoccupation	Characteristic	Criteria	
		title	state
1.1.2. Maîtriser les modes de déplacement et favoriser ceux qui sont les moins polluants	Cohérence urbaine et incitation aux transports propres	Dispositions prises pour optimiser les modes de déplacement (1) notamment par rapport aux pollutions	NR
			R

Figure 4. Instance of preoccupation with associated state.

Sometimes preoccupations can have no matter with the current operation: there are “not applicable” and they can’t be assessed. Argues for be “not applicable” need to be justified by operation specificities. In this case preoccupation is ignored, for instance a preoccupation which is assessed thanks to states R or NR will be considered as reached.

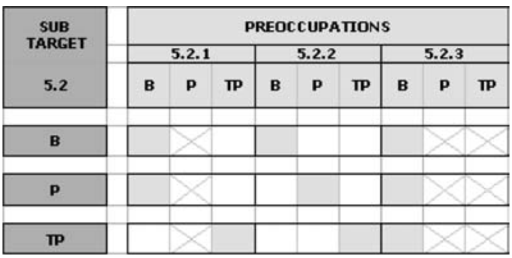


Figure 5. Assessment of a sub target type 1.

3.2.3 *Sub target assessment*

Assessments for sub target are summarized by arrays that display minimum conditions for preoccupations to reach the related performance level (B, P or TP) for sub targets. It still has two ways of assessment according with the type of preoccupation nested:

– CASE 1: For instance this sub target needs to have combination: $5.2.1 - B + 5.2.2$ P $+ 5.2.3$ B to be valued B. The cross means that the related level can’t be reached.
– CASE 2:
– For instance 2 preoccupations Reached confer to the sub target 1.1 a level B.

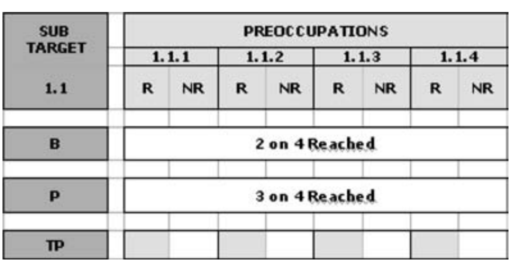


Figure 6. Assessment of a sub target type 2.

3.2.4 *Target assessment*

The two following arrays show two examples of assessment method for targets.

– CASE 1:

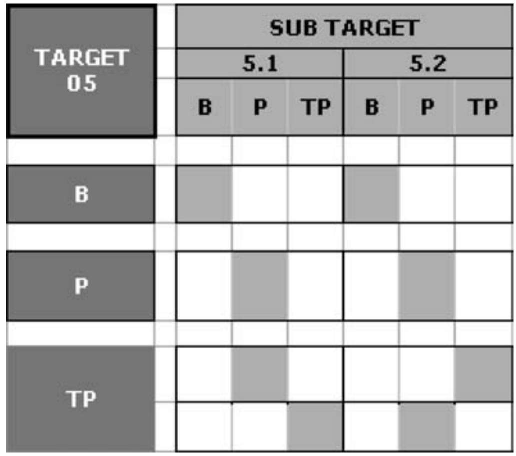


Figure 7. Assessment of a target 05.

It should be noticed that there are two different possibilities for target 05 to be valued TP, the first one is to get 5.1 P + 5.2 TP, the second one is to get 5.1 TP + 5.2 P.

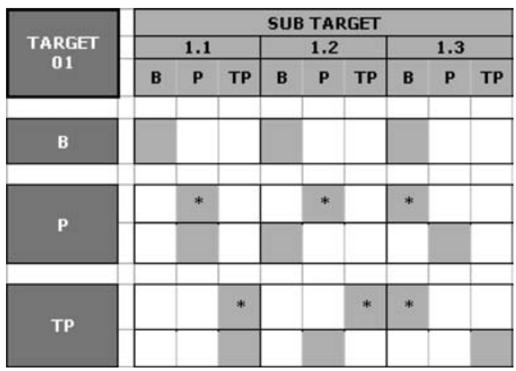


Figure 8. Assessment of a target 01.

– CASE 2:
– * The building owner has to choose this combination if there is no close-neighbourliness for the operation. So there are two combinations to reach TP level, but there is a specific condition implying the choice to one or the other.

3.3 *Global consistency of projects*

HQE has to be assessed at the end of each three phases of a building project (program, design and build) and each step needs to be consistent with the previous one and with aims defined at stating point by the HQE profile. Main element implying this consistence is interaction between targets. If the HQE process needs to be divided into distinct preoccupations to allow a complete assessment of project, some of those items are transversal and their changes can implies positives or negatives changes for others targets.

4 IMPLEMENTATION OF QEB PROCESS

Purpose of this part is to show how model processes describe in the previous section. This extranet project has been developed to run on an Apache2 server using PHP4 and Mysql.

4.1 *Recap of specifications for the assessment part*

4.1.1 *Data preservation*

A complete HQE project represents a lot of data that needs to be saved:

- Project features (durability, type of infrastructure, air-conditioning, thermal regulation …)
- HQE profile for each phase
- Target, sub target and preoccupation value for each QEB assessment of the three phases.

There are about 14 targets, 38 sub targets and 148 preoccupations these figures changes according to the reference.

4.1.2 *Allow to nest many technical certification references in the same tool*

Technical certification references evolve on a regularly base, and a new tool for each new release will not be satisfying. Firstly because of the cost of implementation and then because we need to gather all data across years to get a global and statistic view. All releases have to coexist in the same tool.

4.1.3 *Implement all the logic of assessment calculation for target, sub target and preoccupation*

To match our previous requirements, part dealing with implementation of the technical reference and assessment rules have to be designed independently with core of the tool that remain the same whatever technical reference release. To manage this strong requirement all logic and structure of the technical references is express in a table package, including expression of:

- Hierarchical assessment calculation
- Dependencies with project features
- Interdependence with others target
- Applicability notion for preoccupation according to the project context and the aimed performance of QEB profile

4.2 *Database structure*

Structure of database is spitted in packages, a package gathers tables that work all together and are using to manage a specific job. There are five packages:

- *User* to manage different rights and their related accesses
- *Operation* that gather all features for a building project
- *Technical Reference* which represents a specific technical reference
- *Assessments* to preserve all value for each Target, sub target and preoccupation and which is linked to the Reference package
- *System* to keep trace of user actions and connection

4.2.1 *Technical reference and assessment packages*

Technical Reference Package (Figure 9) is the part reflecting hierarchical structure of targets, sub targets and preoccupations. It contains four tables:

- *reference*: that contains one line by implemented technical reference;
- *target* linked with table reference and sub target;
- *sub target* linked by target and preoccupation;
- *preoccupation*;
- Those tables only change when there is a new release to add.
- Targets values are written in the assessment Package that contains following tables:
- *line* that can be a HQE profile or an HQE assessment gathering e-targets
- *e-target* linked with an id of the table “target” and contains the assessment value
- *e-sub target*
- *e-preoccupation*

4.2.2 *Expression of a “Target”*

The tables “target”, “sub target” and preoccupation have got common fields to process the assessment. These fields are described in this section and “Generic Target” (GT) names these three tables. The target has got text fields to display its name, its description and nota to guide user during assessment. Next sections are explanations of the fields used for the assessment.

4.2.2.1 “expression_type”

To manage to distinguish which type of assessment calculation is used to value GT according to nested sub target values. There are two possible types of expression. The first possibility could be recapped by: “we need to have got 3 sub targets with performance B and one with performance P to reach the level P” (see Figure 6), for this case value of expression_type is 1. The second possibility is “to reach the performance P, the sub target 1 has to be valued with a P and sub target 2 has to be valued with P (see Figure 8), and so, value of expression_type is 2.

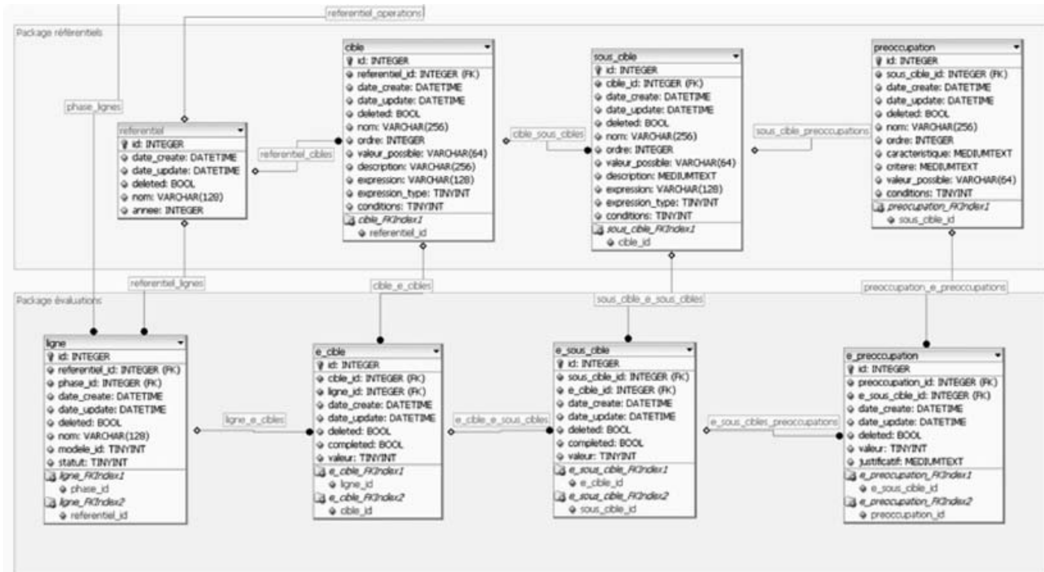


Figure 9. References and assessment packages.

4.2.2.2 "condition" and "condition_value"

As we saw previously (4.1.3), assessment has got dependencies with project features. There are two kinds of dependencies; first one impacts the list of possible values reachable by GT (see 4.2.2.3) and second one impact the assessment expression (see 4.2.2.4). For instance if project have to be RT2005 compliant, target 4 be assess B, only P and TP is allowed and assessment resolution as well is impacted by this project feature. Fields "condition" and "condition_value" allow knowing when and how a project feature impacts a GT. They are filled with a condition number (from 1 to 14) relating a project feature. According to this data a function return a value which is the list number to take into account in the "possible_value" or the "expression" fields.

4.2.2.3 "possible_value"

This field is a list giving possible values that can reach a GT. Listed values are separated with ','. All possible GT states and related values are written in Table 1.

For instance target 14 can't be valued with a performance TP so "*possible_value*" is: (4,5). Preoccupation 1.1.2 displayed in Figure 4, possible_value is (1,2) and for Figure 3, possible_value is (4,6).

In few cases possible values for a GT are depending on initial data of the project, possible_value will contain as many list as possible values for the initial condition. These lists are separated by "#". For target 4 value of this field is: 4,5,6#5,6#5,6, meaning that if the project doesn't have to be compliant with thermal regulation, target 4 can be assess with B but if project has to be RT2005 or RT2000 compliant target 4 could be only P or TP.

Table 1. Possible values for a GT.

State	Performance	Value in DB
Empty	V	0
Not Reached	NR	1
Reached	R	2
Not Checked	NC	3
Base	B	4
Competitive	P	5
Very Competitive	TP	6

4.2.2.4 "expression"

This field allows resolving GT value for both types of expression (4.2.2.1).

Instance of expression of type 1:

4 : 4 x 4 _ 5: 3 x 5 + 1 x 4 _ 6 : 3 x 6 + 1 x 5

This expression can be split into three parts separate by "_". Each part concerns performance indicates at beginning and separate by ":".

5 : 3 x 5 + 1 x 4 means that to be valued Competitive (5 :) 3 sub target minimum needs to be P (3 *x* 5) AND (+) one of them can be B (1 *x* 4).

Instance of expression of type 2:

4 : 4 ,5 ,4 _ 5 : 5 , 5,5 _ 6 : 5 , 6 , 6 | 6 , 5, 6

As the first type, this expression can be split in three parts, each part matching a performance resolution. *6*

: 5 , 6, 6 | *6 , 5, 6* means that to be valued TP (6 :) sub target 1 needs to be 5, sub target 2 needs to be 6 and sub target 3 needs to be 6 (*5 , 6 , 6*) OR (|) sub target 1 needs to be 6, sub target 2 needs to be 5 and sub target 3 needs to be 6 *(6 , 5, 6).*

4.2.2.5 "Implications"

This is the way to express interdependencies between GTs. If GT1 performance impacts on GT2 assessment, denomination of GT1 is stored in the field "Implication" of GT2. When GT1 assessment is achieved a specific function tests resultant value and if result is not consistent a warning is displayed asking user to change the wrong value.

4.3 *End of the assessment process*

At the end of the assessment, when all GT are fulfilled, consistency tests are launched and a report is written out. If lacks or inconsistencies are detected user has to correct them to be allowed go to the next step. Building's owner can export its project into a pdf report gathering all features project, HQE profiles and detailed QEB assessments. This report is around 50 pages length and summarizes all information. When a phase is closed no changes can be made by building owner. Only the follow-up officer from CertiVéA can check the work.

5 CONCLUSION

5.1 *Return on experience*

The service was designed and developed in several steps from mi 2006 to end 2007. It was deeply tested by both CertiVéA and selected panels of users during last term of 2007. First feedback was about knowledge on HQE mark understanding for correct use. This leads to further works on on-going technical assistance during data input by customers.

The service is now opened for commercial use by CertiVéA. First approved construction projects should occur by mid 2008.

5.2 *A similar service for other construction projects dwelling building NF mark*

Regarding the increasing demand for HQE® Approach in other building sector, a similar software tools is under completion for the certification "NF Logement démarche HQE". CERQUAL, a subsidiary of the QUALITEL association, is the official body in charge of this certification. The reference procedure for dwelling building is close to the tertiary building system and CSTB was granted development of a collaborative platform for gathering information about certification process for dwelling buildings. This project is under progress and should be completed by mid 2008.

5.3 *Conclusion*

In this paper, we had a detailed presentation of the capabilities of interactive collaborative platform to support the process for Environmental Quality in the Building sector. This is a new service, recently in operation, with a very promising future, as the number of buildings applying for the HQE® Approach is increasing very fast. The next months will provide feed-back on the performance of the service, and possibly lead to the development of additional extensions.

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Innovation and standards

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EU- project STAND-INN-Integration of standards for sustainable construction into business processes using BIM/IFC

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ABSTRACT: STAND-INN, which is scheduled for 26 months to end late 2008, addresses new manufacturing processes based on IFC standards and performance based standards for sustainable construction with objectives of creating new and more efficient business processes in the construction sector. This will facilitate the sector's great potential for cost reduction and increased productivity and competitiveness, furthering sustainable development. The suite of buildingSMART standards is now being incorporated into major software products and the use of which is now being required by an increasing number of major clients throughout the world.

1 INTRODUCTION

1.1 *Call and project type*

The "STAND-INN" project (integration of performance based building standards into business processes using IFC standards to enhance innovation and sustainable development) was developed for the Coordination Action call "Standards in support of innovative business solutions" FP6-2005-INNOV-8, 15/04/2005. STAND-INN addresses the "Action 1.2.1.7 – Standards in support of innovative business solutions". It focuses on its objective 2: "To facilitate the integration of open standards into business processes", however, addressing also the two other objectives of the call: "To facilitate the integration of open standards into the design of new products and services", and "To stimulate innovation through reference to standards in public procurement".

STAND-INN, which is scheduled for 26 months to end late 2008, addresses new manufacturing processes based on IFC standards and performance based standards for sustainable construction with objectives of creating new and more efficient business processes in the construction sector. This will facilitate the sector's great potential for cost reduction and increased productivity and competitiveness, furthering sustainable development.

The Consortium comprises 28 members from 11 European countries (Norway, Finland, France, UK, Sweden, Italy, Lithuania, Spain, Portugal, Germany, Belgium, and with 5 European– wide networks (IAI, CIB, ECCREDI, ENBRI, CEN), entailing major stakeholders from industry including SMEs, users, R&D and standardization as well as 2 partners from China.

The work plan entails developing guidance material for improved innovation with respect to the IFC based design of business processes (WP1-Action 1, with links to design and performance of building products (WP2 -Action 2), -to sustainable housing (WP3-Action 1 and 2), and public procurement (WP4-Action3), as well as carrying out a series of work-shops on the themes (WP5) and developing handbooks on "best –practice" and pilots (WP6), and policy recommendations to enhance innovation (WP7). Some results will be exhibited in this paper.

2 STATE OF THE ART AND DRIVERS FOR CHANGE

2.1 *The construction sector is in for a change*

The construction sector is strategically important for Europe, providing the buildings and infrastructure on which all other industries, and public bodies, depend. The sector employs more people than any other industrial sector, but because most firms in the sector are small and medium-sized enterprises (SMEs), its contribution to European GDP and its importance for the overall economic performance is often not fully recognized. In all it has been estimated that 26 million workers in the EU-15 depend on the construction sector, comprising 2,5 million enterprises (97% SMEs) and an investment of €910 billion (10%of GDP) (ECTP 2005a).

This sector is now facing a paradigm shift, moving from a situation where the building and building products are considered as physical objects to one where the built assets are service arenas designed to supply and manage a set of environmental and other functional performance services throughout its total life-cycle with changing end user needs. It shifts attention from the traditional focus on hand-over and the defects period, to the years beyond-whether or not the supplier has (e.g. through a public private partnership) a commercial interest in that performance. This paradigm shift, coupled with the drive for customer orientation, sustainability and ICT deployment is regarded as the key drivers for change and improvement in the B&C sector. (ECTP 2005b, c).

2.2 *An inconvenient truth – an unsustainable construction sector*

Global mean temperature coincides with CO2 content in atmosphere. The CO2 content is way above any former level, and it is skyrocketing, causing climate change with disastrous consequences for mankind (IPCC 2007).

The construction sector has a key influence on sustainability (ECTP 2005a). Its environmental impact is high because

- Buildings and the built environment uses 50% of the materials taken from the Earth's crust.
- During their life cycles buildings comprise the largest energy consuming sector with the almost half of the primary energy used and generating about 40% of all greenhouse gas emissions in Europe.
- Waste produced from building materials are the source of 25% of all waste generated.
- The building sector also has a major economic impact (10% of the GDP of the EU).
- People spend almost 90% of their time inside buildings.

This is why the industry – led ECTP so firmly and consistently states "becoming sustainable" as part of their vision (ECTP 2005a) and key targets for their Strategic Research Agenda (ECTP 2005b).

A key success factor towards the adoption of sustainability-related innovative foundations (i.e., standards, concepts, products, and process) in the Construction sector is that the knowledge and information is made available for decision makers and other stakeholders involved in the value and supply chain. It is necessary to provide new information-intensive services in order to successfully bring the knowledge produced (along the process) into its intended application.

Here is where the IFC model comes into play, since it targets the information used (in theory by all actors involved in the building process) to represent a construction product during its entire life cycle.

2.3 *Customer orientation and ICT driven interoperability of the building process*

The inefficiency and lack of information interoperability of the building process is a major cause for high production cost, building damages, etc. A NIST US report (2004) states "Inadequate interoperability in the US Capital Facilities industry costs approximately $15.8 billion annually, representing 2% of industry revenue".

Thus the construction process needs to decrease production costs and increase productivity. It must also change from a supply to demand/user driven focus across the building life cycle (ECTP 2005a,b). To achieve these goals requires business process innovation and a realisation that ICT based building standards provide the 'glue' which can dramatically improve the performance of the value chains.

The process for change is driven by the International Alliance for Interoperability (IAI), which has more than 600 members across the world (www.iai-international.org). The IAI, supports, or oversees the *whole life cycle of developing and deploying integrated project working using interoperable solutions* (Liebich 2007). This has been IAI's reason for establishing the new branding buildingSmart, with the broad scope to support the whole adaptation process:

"buildingSMART is integrated project working and value-based life cycle management using Building Information Modelling and IFCs"

3 BUILDINGSMART – DEVELOPMENT AND IMPLEMENTATION OF IFC COMPATIBLE BIM

buildingSMART is the principal standard for information exchange and sharing across the whole construction life cycle, which is now being incorporated

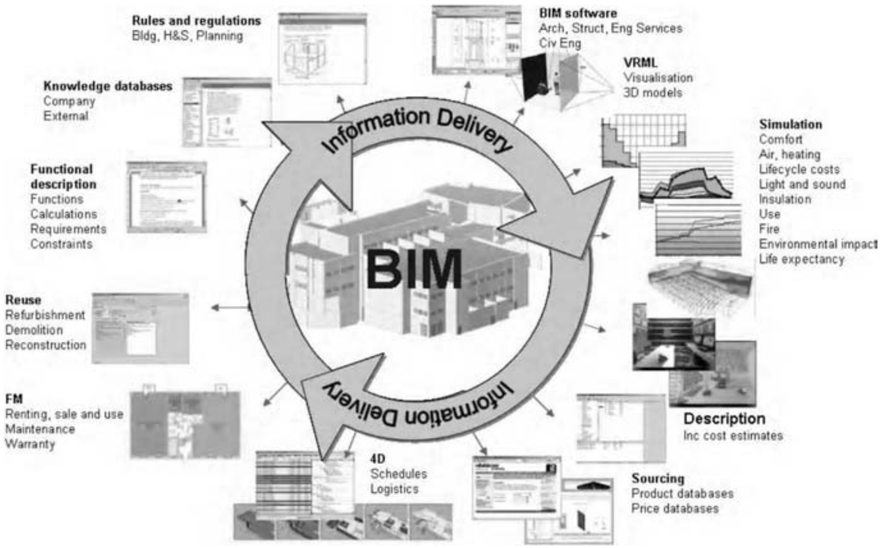

Figure 1. The information delivery over the building life-cycle.

into major software products and the use of which is now being required by an increasing number of major clients throughout the world. It covers all the international specifications (BIM, IFC, IFD, IDM, etc) and technologies developed to meet the vision of IAI. Its adoption can bring about major changes/improvements in business processes for the whole value chain. By providing a facility for shared information, it can provide a catalyst for the change from a contractor/supply driven industry to a more user/demand driven industry, Fig. 1.

3.1 *BIM*

Building Information Modelling (BIM) is a new and promising building design and documentation methodology. BIM is the term applied to the creation and use of coordinated, consistent, computable information about a building project in design, in construction and in building operation and management. The term has been adopted recently to replace 'Computer Aided Design' (CAD) so that the emphasis is placed on 'information' and 'modelling'. BIM is sometimes referred to as a 'virtual building' because it can be used as a simulation of the real building.

A 'BIM' is the collection of objects that describe a building. BIM software applications have been developed using 'object oriented' methods. This means that they work with 'objects'. An object represents an instance of 'things' used in building construction, that can include:

- physical components (e.g. doors, windows, pipes, valves, beams, light fittings etc.),
- spaces (including rooms, building storeys, buildings, sites and other external spaces),
- processes undertaken during design, construction and operation/maintenance,
- people and organizations involved,
- relationships that exist between objects.

Within BIM, the geometric representation of an object is an attribute. This differs from CAD which works with geometry items like lines, arcs and circles from which geometric representations of objects can be created and stored.

BIM covers geometry, spatial relationships, geographic information, quantities and properties of building components (for example manufacturers' details). It can be used to store the results of analysis and modeling of engineering requirements. BIM can be used to demonstrate the entire building lifecycle including the processes of construction and facility operation. Quantities and shared properties of materials can easily be extracted. Scopes of work can be isolated and defined. Systems, assemblies, and sequences are able to be shown in a relative scale with the entire facility or group of facilities.

Increasingly, BIM can also be used to support knowledge rich applications including:

- Sustainability analyses including building assessment (such as LEED, BREEAM), energy performance declaration, life cycle costing, etc.
- Requirements checking through ensuring that requirements expressed by a client are met by the design or that design requirements are met by construction.

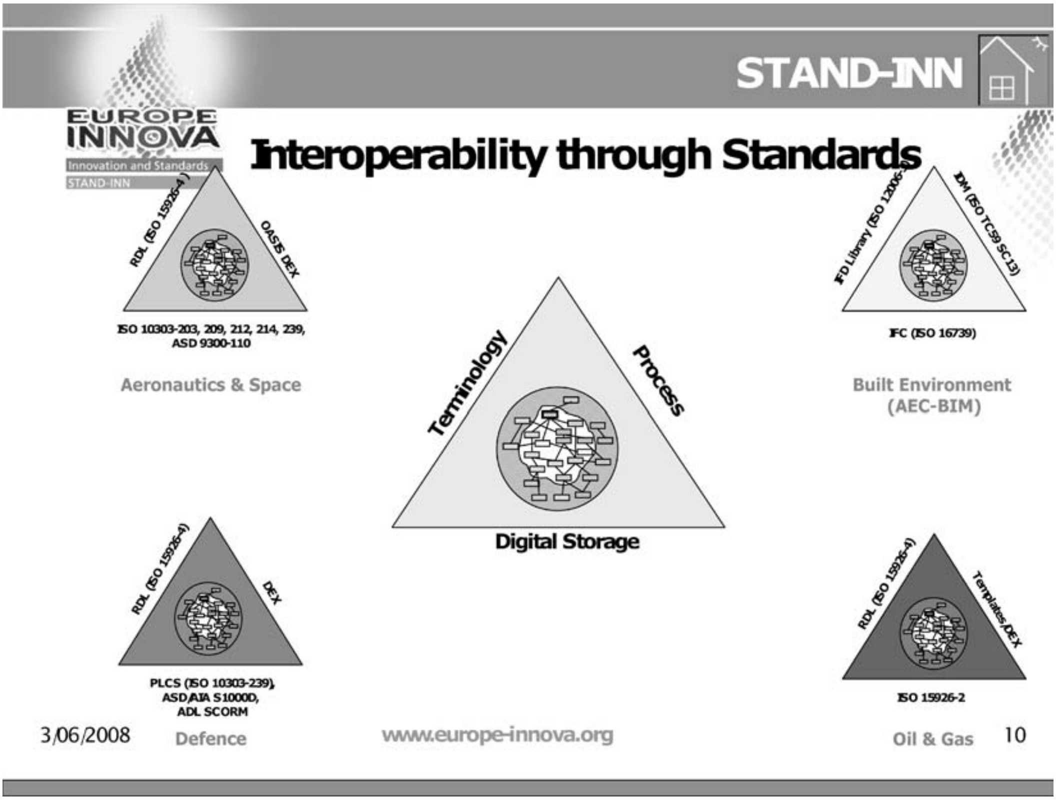

Figure 2. The interoperability triangle of standards for major industries.

– Checking designs against statutory requirements like building codes and regulation.

A BIM is a repository for digital, three-dimensional information and data generated by the design process and simulations—it ' s the design, fabrication information, erection instructions, and project management logistics in one database. The BIM will exist for the life of a building and can be used to manage the client's asset.

An integrated BIM stores all the building relevant information during the total life-cycle of the building and provides access to that information for participating members.

A recent study by EraBuild shows that industry is gradually starting to use the concept of BIM, and that architects are the most adaptive to the new technology (Kiviniemi et al 2007). The major construction companies in the Nordic countries have all adopted BIM technology, but so far to a lesser extent the IFC compatible BIM.

3.2 *IFC, IFD and IDM*

In general, to enable interoperable flow and sharing of information contributing to the creation of a Product Model, three specifications/standardisations must be in place. These are;

– An exchange format, defining HOW to share the information. IFC (Industry Foundation Classes) (an ISO standard in development) is such a specification.
– A reference library, to define WHAT information we are sharing. The IFD Library (International Framework for Dictionaries) (an implementation of ISO 12006-3) serves this purpose.
– Information requirements, defining WHICH information to share WHEN. The IDM (Information Delivery Manual) approach (also an ISO standard in development) forms that specification.

This is the triangle of standards forming the basis for the product modelling that has been developed and implemented in other major industries, see Fig. 2. Now the AEC industry is at the core of change, and this change will facilitate the needed compliance with sustainability, user requirements etc.

The development, maintenance, implementation and dissemination of IFC and IFC enabled products is part of the buildingSmart initiative of the IAI.

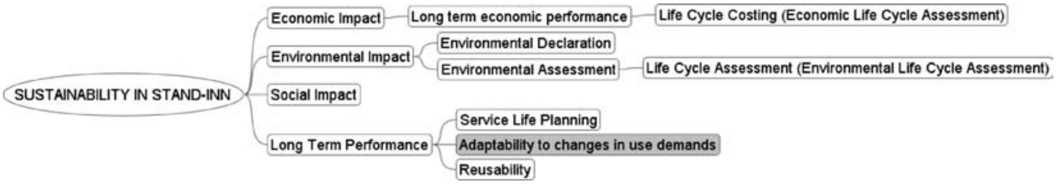

Figure 3. STAND-INN taxonomy for sustainability.

IFCs are the result of an industry consensus building process. They contain common agreements on the content, structure and constrains of information to be used and exchanged by several participants in construction and FM projects using different software applications. The result is a single, integrated schema (or data model[1]) representing the common exchange requirements among software applications used in construction and FM specific processes.

The term IFC is used for the underlying schema and for data content structured according to the schema. The IFC schema is an open, publicly available and industry-wide standard for structuring and exchanging construction and FM specific information among software applications. The latest IFC extension release, IFC2x3, was published in year 2006.

In its simplest form IFD is a mechanism that allows for creation of multilingual dictionaries or ontologies, and would probably better have been named International framework for Ontologies. The name is used both for the IFD library and for the organization running and maintaining it. The model itself is pretty simple seen from a implementers view but it is proven to be very flexible and can therefore result in several different implementations. The structure of IFD is given in ISO 12006-3, that was formally published in April, 2007, and is a result of many years of standardization work by the ISO TC59/SC 13/WG 6 work group. Populating the IFD library is now a core activity. More info available at http://dev.IFD-library.org.

The purpose of IDM is to define the information that one AEC/FM industry user needs to provide to one (or more) other AEC/FM industry users to support their work. This means that IDM delivers information at specific points in the business process. As well as defining the information that is needed, IDM also includes the idea of a 'Manual'. That is, it gives guidance to users on providing the information both at a general level and specifically for individual software applications. The aim is to capture all of the information for all business requirements for the whole building lifecycle and for all building project participants. More info is available at http://idm.buildingsmart.com.

[1] The term "schema" is used in order to avoid the confusion between data model and project model.

Basic information and state of the arts reports about BIM, IFC; IFD and IDM's have been developed by the STAND-INN project (Wix et al 2007).

4 SUSTAINABILITY ASPECTS AND IFC SUPPORT

In order to assess the integrated performance of buildings it is necessary to regard a building as a whole with required performance and functions to fulfill. One of the objectives of STAND-INN is to integrate environmental indicators with BIM/IFC following the scheme of things presented in international standards dealing with environmental aspects of buildings.

Recently, CEN has established the standardisation work 'Sustainability of construction works' under the mandate 350 (CEN 2005), building also on the key features of all relevant ISO standards in their drafting. The standards will describe a harmonized methodology for assessment of environmental performance of buildings and life cycle cost performance of buildings, as well as the quantifiable performance aspects of health and comfort of buildings.

The primary standards and aspects of sustainability are considered in WP2, (Trinius 2007), and the aspects cover Economic, Environmental, and Social impacts as well as the Long Term Performance (related to Reusability of buildings, Adaptability to changes, and Service Life Planning), see Fig. 3.

The information needed for sustainable building design and construction is not only data in the form of 'environmental indicators' but also data about building site, local environmental conditions, technical performance of building components and systems etc., knowledge about the behavior of building components in alternative conditions, information about needed measures of care and maintenance etc.

All these areas are important. The aspects and some of their contents is presented in different phases of the building process, as shown in Fig. 4. Even though the BIMs are presented here as separate models, it must be noted that the information exchange standard ensures the interoperability between different information models. In practice, some of these models may be as one model.

Wix et al (2007) collected instances on the usage of BIM/CAD and application software for sustainability

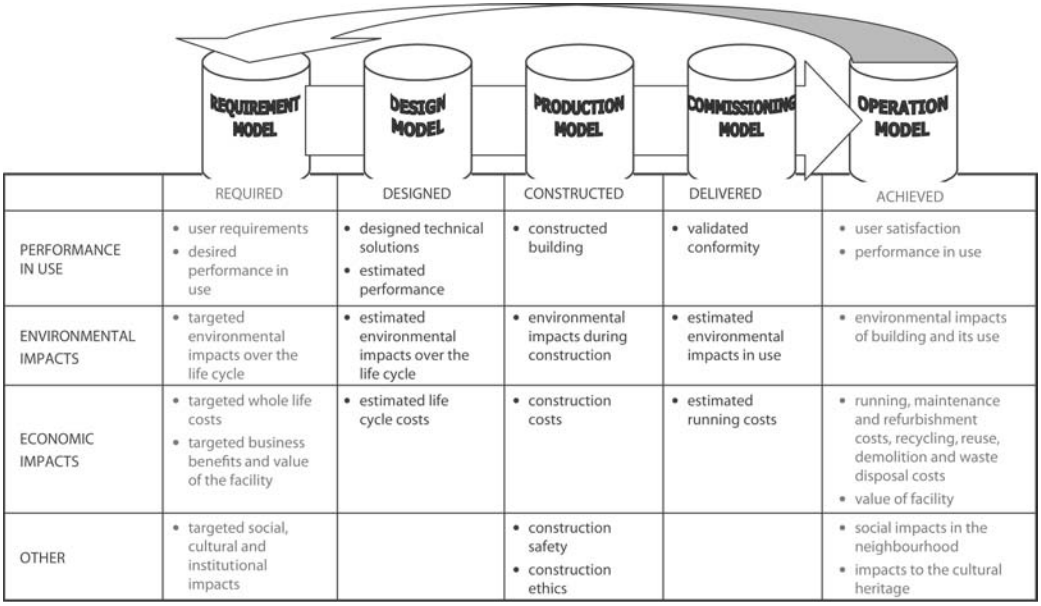

Figure 4. Innovative sustainable building and building information models.

on projects to determine the extent of use, successes obtained and possible potentials.

Sustainability applications fell into two groups. The first group includes those applications that are easily amenable to BIM integration whilst the second group includes those applications whose benefit has yet to be fully realized. Energy performance declaration and life cycle costing fall into the first category as these can be more easily understood in the context of current software use. Environmental impact, service life and other applications fall into the second category. But this second group of applications can offer major benefit as is shown by the best practice examples.

5 CONCLUSIONS – POTENTIAL IMPACT

Some STAND-INN conclusions so far

1. The IFC and use of BIM have great potential for value creation during the whole life of buildings at least in the following areas:
   - Focus on customer and end-user requirements and sustainability within the building process and life cycle phases
   - Increasing transparency in the decision-making process and re-engineering the building process with new business opportunities for new and existing actors
   - Cost saving to all actors and a better project economy
   - Improved possibilities for early stage analysis about: best practice design, construction cost, energy consumptions, environmental impacts, lifecycle cost, performance in use, flexibility, adaptability, indoor climate, usability and maintainability
   - A comprehensive and common international knowledge model database with standardized ICT tools, objects and communication rules and available best practices examples.
2. Standards act as catalyst for innovation and the integration of sustainability standards onto the suite of open IFC standards facilitating BIM, will greatly enhance the construction sector's need towards sustainable development.
3. Government (public procurement) plays an essential and decisive part in this transformation of the construction sector, acting as the policy maker, regulator and by far the biggest customer, thus as the key player driving innovation and sustainable development.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

B.I.M. Towards design documentation: Experimental application work-flow to match national and proprietary standards

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ABSTRACT: The increasing influence of BIM approach for the practice of architectural and engineering design is enhancing a progressive consciousness of the limitations, imposed to the practical implementation of BIM in professional business, by the actual asset of the technical standards and rules. Assuming the real operational scenarios of the Italian context, the domain of research object of this paper explores the solutions' definition and the related production of design documents, following the B.I.M. modeling approach along two major directions:

– the application to a real business case operated within a middle-size building Company, a BIM- modeled design to be experimented as the occasion for connecting geometry and technical solutions' details with the SQL-based accounting system, by means of IFC Interoperability;
– the connection with an experimental BIM – IFC Design Library, developed with Assimpredil-Ance, to match the requirements of the newly issued UNI technical Norms concerning energy saving and acoustic insulation.

1 OBJECTIVES

The main objective of the application experiment reported in this paper is to explore a reliable approach to the design of multi-layer building solutions through BIM approach and related software environments, with detailed attention to the exterior envelope and floor-packages design for residential and office buildings.

The experiment to be implemented is aimed at tackling the limitations inherent to many CAAD software packages for the BIM modeling of multi-layer compound components or building parts. The limit actually consists of the difficulty of managing each individual layer of the compound as individual 3D parametric object, as one individual member of the compound, representing and operating it with all the range of opportunities offered by the BIM environment, associated with the features supplied by conversion into IFC Entities, until their import into digital simulation environments.

The objective pursued by the practice of this Case Study is to explore a BIM design procedure, by the available CAAD tools, that enables the association of the data sets concerning nature and performances of already known building solutions – or specific individual Norms–compliant components and materials object of laboratory experimentation – described in the reference Design Library, in spite of the limitations of the modeling software.

2 THE EXPERIMENT CASE CONTEXT

2.1 *The Italian Scenario*

The Italian scenario is recording relevant dynamics:

– in the domain of building Norms and Regulations, based upon a strict collaboration program issued by the Ministry of Public Works with ANCE (the National Builders Association) and UNI (the Italian Standard Body): new Norms are being issued defining a common shared classification terminology, coding system, characteristics and performance, closely related to the European Standards initiatives related to CI/SfB[1] classification and aware of the awaited IAI – IFC interoperable technology's adoption;

[1] CI/SfB is the classification system most widely used by architectural specifies. The system has been in operation for more than 30 years and is the industry standard (Swedish SfB – the English and Dutch translations Nl/SfB and CI/SfB).

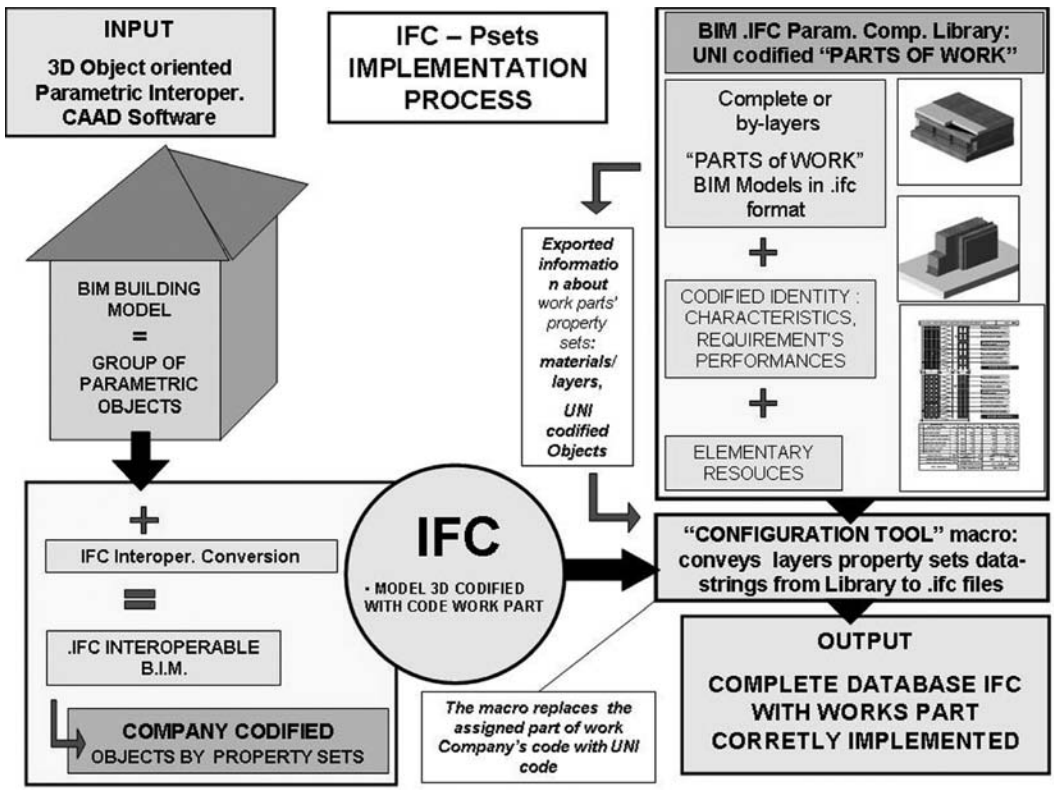

Figure 1. Scheme of the IFC Psets implementation process.

– in the domain of design QTO documentation, by the specializing of many competing software products, the interest of which in matching IAI – IFC interoperability requirements is increasing.

2.2 *Meeting limitations*

– Some of the more frequent B.I.M. based architectural modeling software products cannot yet fully define a multi-layer building's part of work as a compound architectural element (e.g. a building envelope with thermal insulations, supporting elements, both sides finishing), thence preventing the direct association of the related specific character and performance to each layer: this results into the inability to develop nor a fully correct and complete "list of objects" to be used as the reference base to develop material resources' QTO, nor the direct development of the depending design documentation into the following items, nor a facilitated via software simulation for the main behavioral aspects of the operating building;
– Too frequently the B.I.M. based architectural modeling software products cannot match the Measurement systems inherent to the building Norms and Regulations of Administrative Institutions, even less the typical accounting systems of building Companies, based upon its entrepreneurial view of resources, description of works, building actions, etc.: though taking into account the obvious huge difference among National and Regional Norms, a sort of "common Standard Middleware" is needed;
– the simulation of the thermal character and performances of the design architectural solutions, considered at the most relevant scales, of the entire building configuration (architectural volume and cardinal orientation, shape, functional type, occupation…) and at the scale of its main components (exterior envelope, floors, roof…) must refer to reliable performance data from the technical Laboratory testing upon material applications; this obvious constraint condition produces difficulties for specific envelope components simulation, specially if solutions are designed by innovative configurations of already known materials or associations with new ones.

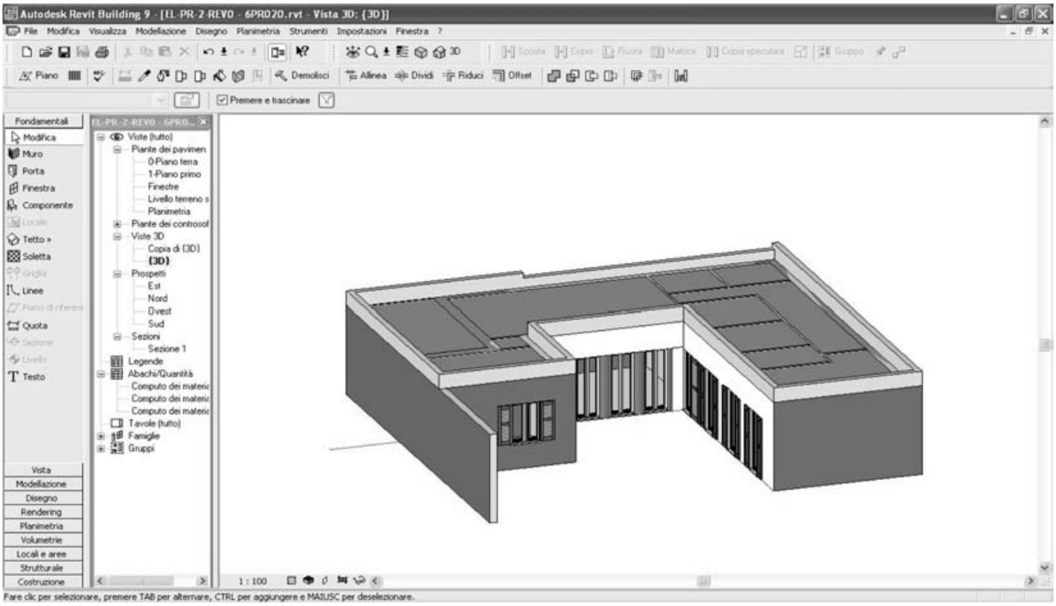

Figure 2. The Company's original residential building BIM object of the experiment.

2.3 *The chosen approach and methods*

The approach experimented here proposes a pathway to assure the richness of required features for building solutions through a phase-by-phase increasing of attributes along the design process.

The assumption practiced is that the data sets defining characteristics and performances of multilayer compound building solutions, conserved in the associated Design Library, can be "conveyed" to the BIM model of the building during a postponed following design phase, separate from the architectural design of the building as the entire system.

Id est the materials and components can be stored in the Design Library both as individual elements or as multilayer compounds, defined by the whole data sets of attributes relating to characteristics and performances.

The applied method operates by the possibility of assigning different roles and times to the definition of the building parts versus the building body as a whole comprehensive system: in the architectural configuration phases the characters of the main components can be represented (or also "symbolized") as elementary 3D, Object Oriented, parametric simplified BIM models (e.g. a single-layer envelope or floor packages).

In the sequence of design decisions, further definition of characteristics and performances can be supplied by connecting the data sets of Norms-compliant and IFC standard based elements in the Design Library, of the required level of complexity, the correctly structured attributes of which can be associated by a direct effective procedure.

The illustrated approach is meant to supply the required levels of definition of the data to the BIM building model in terms of "content enrichment" of the previous partially defined component objects, matching the operating condition of the CAAD modeling tools with the design requirements, refined in the design sequence by adding progressive sets of attributes required for the related decision making and design documentation authoring.

3 THE APPLICATION CASE STUDY

3.1 *Tackling limitations*

The experimental application case study presented here is the object of an on-going business research contract stipulated between a middle-size building Company and ProTeA Research Unit; the main research content is the implementation of an IFC Standard based process to match the very heterogeneous instances of the Company's actually implemented procedures. The present working procedure implemented for building construction entrepreneurial initiatives is organized as follows:

– architectural design is both or an outsourcing acquired service supplied by the client, or developed as in-home activity, by the Company's technical bureau, which develops in every case the

executive detailed and workshop design for the building site, assuming the responsibility to define building materials, components, construction technologies and on- site planning; after a long habit in using vectorial CAD environments, recently the technical bureau implemented a BIM- based IFC interoperable CAAD system;
- the whole Company's planning and administration activity is based upon a traditional robust SQL language computation system implemented by a proprietary software-house; it operates the classification of every resource present or supplied to the Company, including personnel, operating means, warehouse stocks, supplied commodities and services, financial resources, economical accounting, etc. It is structured in the form of a hierarchical tree, into two main sections; the first listing all the basic resources present or purchased by the Company at the most elementary level of granularity, organized in a hierarchy of "Families", "Sub-families" and single items relating to the specific content; the second lists the 'building work parts" aggregated as the result of merging the elementary resources with the operating equipments, "building or organizing actions" of every kind (specially for the complex technical solutions based on multi-layer concurrent materials and labor resources), from the design and QTO services to on-site operations, including administrative labor performances. The system as a whole supports the Company's ability to control every level of its activity by its operational and economical evaluation, in order to choose the most appropriate and productive building construction practices and constitute the base for the Company entrepreneurial bidding.

The two systems used to be completely separated, so that the implementation of the data sets produced for the design documentation – in spite of the BIM formats issued by the technical bureau – had to be manually input into the SQL administration system in order to develop the whole design documents following architectural and building-technique decisions: QTO, cost estimate, building price offerings, bidding documents, etc.

The same difficulty were met for the feed-back issues from the operated construction activity outputs, on-site accounting, design changes and adaptations, "as built" documents repository, statistical accounting could not profit of interoperability for the data sets exchange.

3.2 *The experiment's deployment*

The research contribution performed by ProTeA was meant to establish a direct operating connection between the above described systems, by means of implementing an IFC Standard- based data exchange

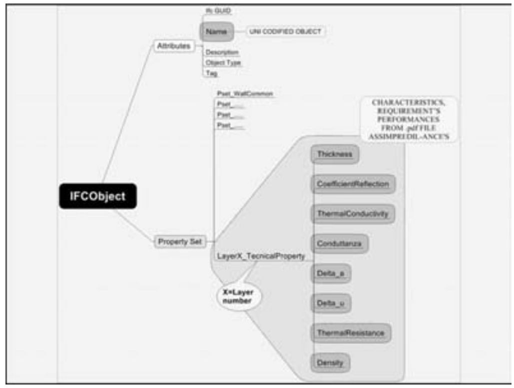

Figure 3. Enriching by attributes the IFC object's files.

platform, enabling the direct transfer of the BIM model "list of objects" – serving as the base for a correct QTO, into the SQL administrative systems – thence inheriting the whole classification data sets embedded in the Company's computation system. The exchange platform is based upon the conveyance of the architectural model's data sets (geometry, quantities, attributes of every object as a member of defined component-families, etc..) to the administrative SQL computation environment, via the addition of a number of data fields supplying the identity analogies or proximities between BIM objects and the in-home Company's classification of resources and activities.

Here are the practiced main phases of the experiment's workflow sequence:

1. a design scheme for a small size residential building, chosen as experiment- bed within the smallest on-going project by the building Company, is developed into a B.I.M. model (3D, Object Oriented, Parametric) than converted into IFC 2x3;
2. a procedure to extract the entrepreneurial version of a professional "Quantity Take Off documents" from the model's "list of design-implemented objects", supplied by the B.I.M. modeling software, operated by tackling their limitations as strictly material-object oriented enumerations, towards a business process-aware measurement, expressed by Company's in-home classified resources' terminology, establishing a proprietary B.I.M. parametric components Library;
3. in parallel with operating the Company's applied experiment, an exemplary "B.I.M. parametric components Library" has been developed in collaboration with the ASSIMPREDIL – ANCE, the Lombardy Region chapter of the National Building Constructor's Association; the eighteen "Building parts of work" are defined in compliance with the new UNI coding Norms, according to the set of performances assessed by CNR (the Italian National Research Council) by laboratory experiments.

4 THE CHOSEN SOLUTION PRACTICE

A particular condition was imposed to the research work-flow by the circumstance of the specific CAAD product implemented in the building construction Company: the peculiarity being that the specific output BIM format was not following the .IFC standard structure for the BIM objects' and attributes' archiving; on the contrary a proprietary scheme is applied to properties description, though based on the .IFC Standard ontology.

The BIM model format anyhow allowed the enrichment of identity and attributes of objects by eventually writing added properties in dedicated codification fields available in the identity-encoding string of character.

As the result of these operating features, an individual property set could be edited for each of the BIM objects, aimed at including the key-information connecting them with their assigned "Alias Name" in the Company administrative system, thence identifying the BIM objects as "Building work parts".

4.1 *Levels of "Granularity" describing building work parts.*

A relevant problem occurred while structuring the property sets' data base: the most effective level of granularity to be established for the description of the Building parts of work, in order to match the Company's requirements of compliance with their hierarchical tree-like classification scheme for their whole resources' administration and construction process.

Many robust reasons have motivated the choice to define the Building work parts' by the most elementary possible level, i.e. at the level of individual resources like basic materials and components: the scope is to support the consequent QTO and economical estimation of fundamental works like the building envelopes, flooring and roofing technical solutions, the performances of which are based upon the association by layers of different material.

It is also evident that innovation issues concerning these work parts will require or partial adaptations or radical changes due to new materials' or experiment results assumptions into the multilayer technological alternatives.

4.2 *A design multiple-solution and innovation friendly*

The ability to describe, codify and transfer the whole information set representing a multilayer building parts – compared with its competitor technological alternatives made by different materials or related functional association – is strategic to the scope of optimizing energy saving performances and interior comfort conditions.

In this application case, the CAAD modelling Software was able to represent the geometry of multilayer Building work parts, received the input of the layers' identification property set added to BIM objects, but the related information was lost when converting into the .IFC format; only the "designated Name" for each of the single layer-object was conserved, also depending on the ability of the IFC Standard version 2 X 3 features.

Thence comes the necessity to define a coding solution able to operate at the same level of the Company's resources' classification system, i.e. to describe the Building work parts by elementary layers, opening a further codification issue to "translate" the in-home data base structure into a new UNI-compliant "Alias identification".

4.3 *One of a range of possible solutions*

One solution was chosen among the range of possible approaches, assumed as the most suitable both for the specific application case and for the continuity of the design-modeling, building construction, operating and maintenance process: to operate the encoding of the Building work parts by computing resources "external" to the BIM modeling environment, where the "Names" of the functional layers only are designated by association to the chosen materials applied.

The core coding activity (both for the whole Building parts of work and / or for any of the compounding layers) is operated in the phase following the design modeling and the export of its geometry and natively defined attributes as a member of a conventional BIM–family. The "layer by layer" attributes' encoding occurs when the need of the related information reporting the individual and associated property sets are required by the QTO and Estimating documents issuing phase: encoding of attributes is operated through the "query into a model server system", i.e. a relational data base in which the whole resources' system is described in .IFC format. The implemented solution appears to be the most preferable in order to balance the limitations of the BIM modeling environment associated with its peculiar .IFC conversion features, with the Company's management requirements and the necessity to lay the experimental foundations for a full compliance with the National UNI Norms classification system.

5 THE SOLUTION'S IMPLEMENTATION PROCESS

Preliminary Phase 1: Setting up the operating environment.

An on-purpose Resources' Library is set as the reference system for structuring the whole information set describing both elementary resources and complete

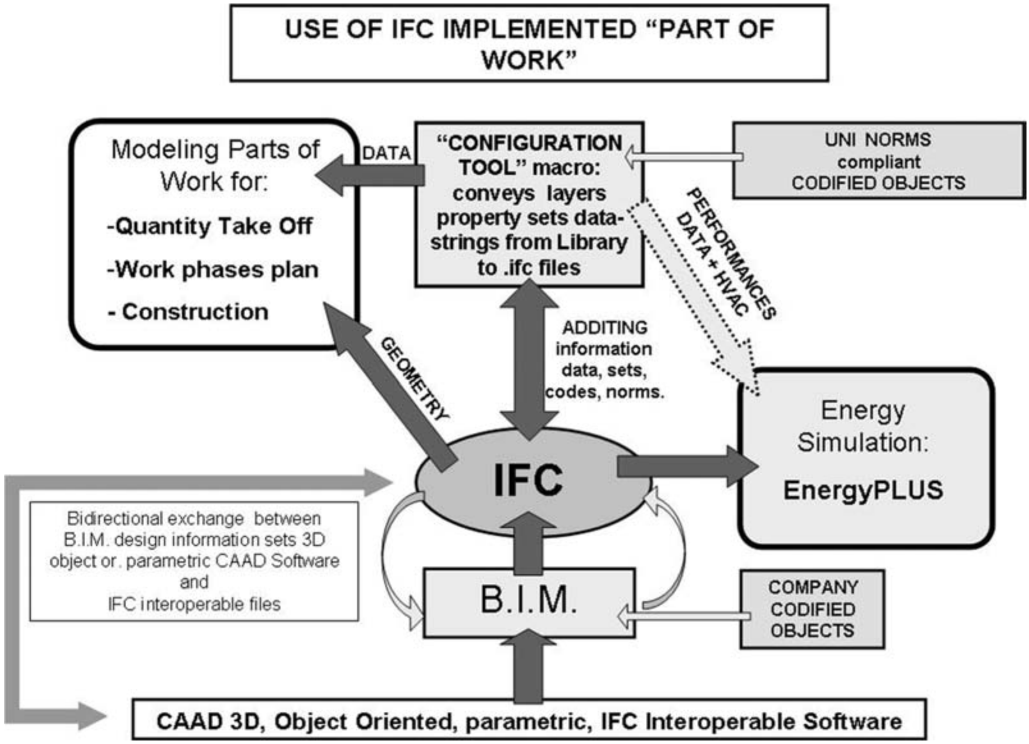

Figure 4. Schema displaying the BIM-IFC parametric component library navigation.

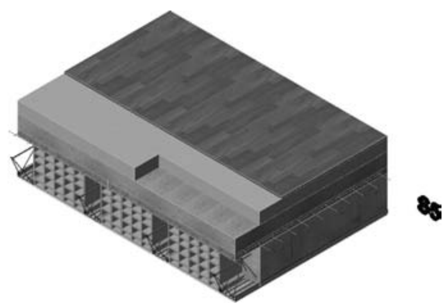

Figure 5. One of the library implemented complete Parts of Work; the floor S5.

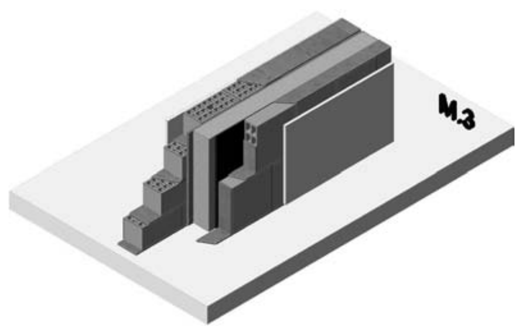

Figure 6. One of the library implemented complete Parts of Work; the envelope wall M.3.

Building parts of work in compliance with UNI Norms (as in chapter "An Exemplary B.I.M. – .IFC Parametric Components Library");

Preliminary Phase 2: Issuing parts of work Layers' Property Sets:

Each of the layers is identified by connection to a "LayerX-TechnicalProperty" Property set (where "X" is the identity number of the specific layer); the information contained in this P. set will be enriched with the string of characters reporting the others required identity coding fields and technical specifications (IFC "TechnicalProperty"):

- Thickness
- Thermal Conductivity
- Conductivity
- Coefficient Reflection
- Delta_a
- Delta_u
- Thermal Resistance Density

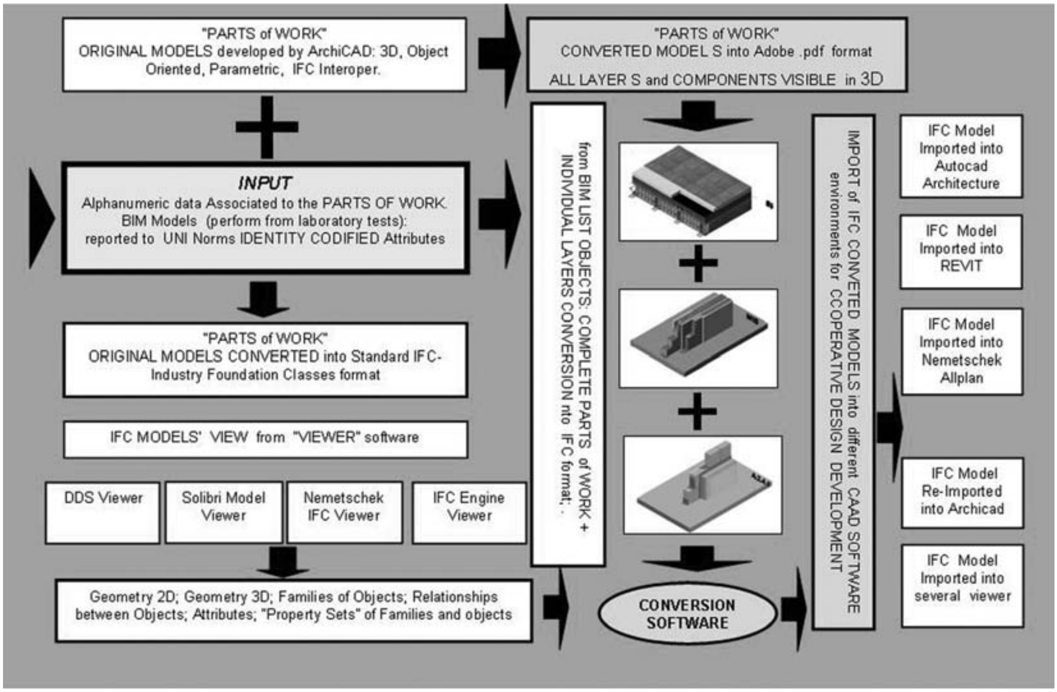

Figure 7. The BIM-IFC parametric component library conception scheme is aimed at demonstrating IFC application's.

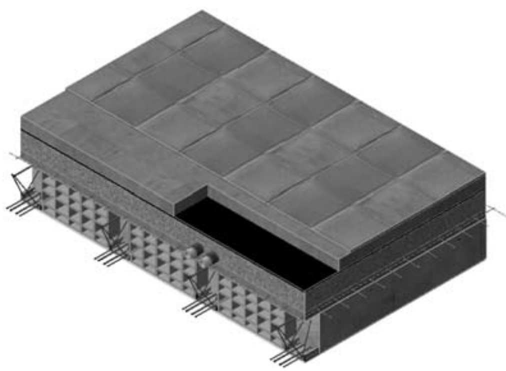

Figure 8. The S2 floating complete part of Work.

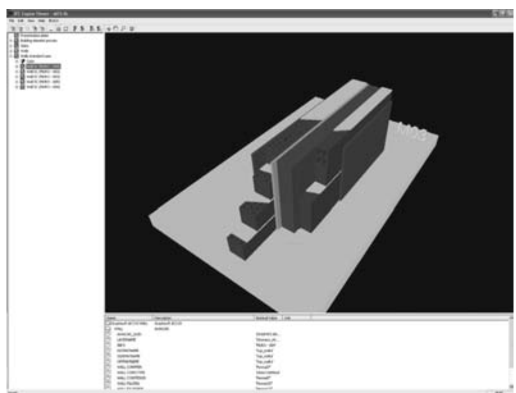

Figure 9. The M03 wall IFC format.

Preliminary Phase 3: A "Configuration Tool":

The necessity of optimizing the data transfer between the two software environments, requires the implementation into the computing procedure of some "automation" features: a coded–identity configuration and assignment routine, a "configuration tool" able to associate the building parts of work compounds (resulting from the assembling of elementary coded resources in form of individual layers) , or in absence of the exact correspondence, of the chosen proxy elements from the Company data base. The "configuration tool's" task is to translate the Company's in-home identity code into the UNI Norms-compliant identity code, connecting the Company's proprietary system with the National public works bidding environment.

Operating Phase 4: Merging the data-sets:

In order to assure the searched condition for the merging of the two associated data sets, it is necessary to configure the coupling of data from the BIM model

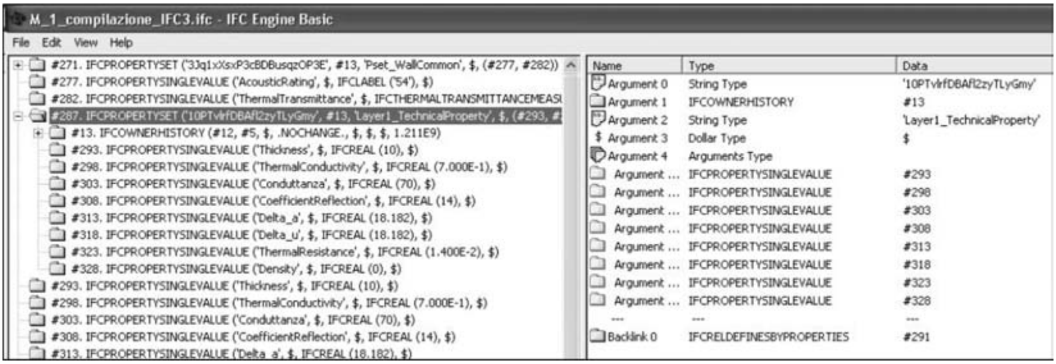

Figure 10. IFC code script for the layers attributes.

with the resources' identities individuated in the SQL administration Company data base (related towards BIM as "exterior" information items), via the assignment of new added 'code fields' to the string defining each of the BIM objects.

The resulting "exterior" files in TXT format, are displayed into two parallel columns designated as "coded Identity" and "Description". In the first field, the code corresponding to the resource's identity in the Company data base is recorded, in the second field a brief description of the same resource is reported.

The creation of this file is operated within the Company SQL data base, than it is exported in .txt format into BIM modeling software; within this destination environment the fields recording additional properties for each of the objects that now can be configured can become the vehicle of a double parallel objectives: only the first one belonging to this phase, i.e. to associate to BIM objects the Company's in-home proprietary identity, while the newly issued UNI Classification Norms compliant coded Identity being added later in the process;

Operating Phase 5: Conversion into .ifc:

The above mentioned BIM object file, "enriched" by the added coding information is converted into an .ifc 2X3 format file;

Operating Phase 6: The aid of the "Configuration tool":

Operating by the "Configuration Tool", finally the UNI Classification Norms compliant coded Identity is **substituted** into the "enriched" .ifc file; the awaited result of the process is that the implemented system is enabled to work as client/server organism, within which a number of opportunities for the creation of on-purpose Property Sets is possible, aimed at specific tasks as detailing or design-documentation production, or building process enhancement, etc ., thence opening up the perspective of coupling the in-home administrative systems with the design modeling and National bidding legislation.

Operating Phase 7: enabling layers' "content enrichment":

The above described additional properties' creation phase was made possible by testing the software environment's ability to support the added properties through their configuration as attributes of an .IFC file, via the 'content enrichment' of its property sets. The application of the attributes to the design model's object is practiced through operating a data selection and implementation directly from a video-displayed list. After the accurate analysis of the structure of IFC code, aiming at understanding the implicit relationships inherent to the description of attributes defining the information flows, once defined the necessary set of properties for the objects' files, a specific on-purpose SQL language data base has been implemented, exterior to the BIM environment but correctly interfaced interface with the .IFC files, enabling a QTO computation based on Company cods and description.

A number of input tables were filled-up with the sets of data originated within the BIM model, converted into the .IFC format; the chosen sets of relevant relationships have been translated into "queries", enabling the required vision of the model in terms of Company's system coded resources.

6 INTRODUCING THE CODING "CONFIGURATION TOOL"

The "configuration tool" operates on the .ifc files three tasks: data sets' research, control and updating:

Step 1 – reading the XML code of the .ifc files, searching for the peculiar properties marked by the attribute representing the in-home Company's coded identity string of characters. The properties' set will be attributed or to the building parts of work as a whole object, or to the individual materials/functional layers compounding the layers of the parts of work.

Step 2 – The control-operating step consists of the translation of the different in-home Company's codes into the correspondent UNI Norms coded identity: the reference example is the above mentioned and below reported B.I.M. – .IFC Parametric Components Library. Through this procedure the correspondence between the in-home Company's data base and the National system is established.

Step 3 – Through the CAAD environment it is possible to codify into the BIM both the compounded building parts of work and the individual materials/functional layers. On the same moment when the .ifc file is updated by attributing the new coded identity, the "Configuration tool" will have to face the following different operating conditions:

A. *The compounded building part of work* ***is not*** *codified – but the individual layers* ***are already*** *codified;*
B. *The compounded building part of work* ***is already*** *codified – also the individual layers* ***are already*** *codified;*
C. *The compounded building part of work is* ***already*** *codified – but the individual layers* ***are not jet*** *codified.*

During the ***Step 3*** execution:

– the ***A***. operating condition can be solved by a simple updating of the identity code attributed to each and every one of the layers of the building part of work, which will result already structured and described in detail.
– the ***B***. operating condition require es the choice of a priority order to be established, on the base of which the "configuration tool" will analyze the in-home Company's coded identity of the compounded part of work, will find out the correspondence with the UNI coded identity, thence will update the coding identity for the compounded building part of work. In the same time, a code-control task will be performed: assessing the perfect correspondence between the materials/layers of the BIM part of work with the exemplary model contained in the B.I.M. – .IFC Parametric Components Library. In case this condition should not be satisfied, the "Configuration tool" will execute a correction on the .ifc file by inserting the chosen appropriate materials/layers list stored in the Library.
– the ***C***. operating condition has to be solved by using the embedded ability of the "Configuration tool" in directly managing the .ifc file.

The ***first*** action consists of updating the properties connected with the in-home Company identity code, by attributing the UNI code;

The ***second*** consists of the implementation of the chosen materials/layers compound into the part of work that has not yet been attributed its layers, by implementing the selected solution included in the B.I.M. – \.IFC Parametric Components Library.

At the completion of the above described steps, the information sets related with the materials/layers have to be added to the definition of the chosen building part of work (e.g. the typical "IFCWALL") by implementing an on-purpose string ("IFCMATERIALLAYERSET") once more imported from the Parametric Components Library. Here are the action-steps to be performed:

1. reading the .ifc file from the Parametric Components Library,
2. searching the property sets defining the materials/layers (see: ***Phase 1: issuing parts of work Layers' Property Sets:),***
3. creating the necessary number of IFC coding lines to implement the instructions (layers are codified as "IFCMATERIAL"), like shown in the below reported example:
4. applying the created "IFCMATERIALLAYERSET" code lines to the selected Building part of work described in the.ifc file (the above mentioned example: "IFCWALL").

7 AN EXEMPLARY B.I.M. – .IFC PARAMETRIC COMPONENTS LIBRARY

A significant phase of the IFC conversion's application to a real business case is occurring in late Spring 2008, when a book concerning the new CEN-compliant Norms issued by UNI (the Italian Standard Body) in the domains of energy saving, carbon gas limitation and acoustical protection for buildings, is published by Assimpredil-Ance, the Association of building construction Companies of Lombardy Region : "*Efficienza energetica e requisiti acustici degli edifici"* [2]. As the title explains, the book aims at updating construction companies and technical decision-makers upon Norms-compliant design and construction solutions object of experimented practice and performances' assessment by laboratory tests.

A great opportunity was offered by this publication for the diffusion of the Industry Foundation Classes Standard based interoperability consciousness: the Authors required the exemplary parts of work with their attributes to be represented by BIM models and the related IFC-converted format, thence finally

[2] "Efficienza energetica e requisiti acustici degli edifici. Percorso di aggiornamento per costruttori e tecnici su adempimenti normativi, compatibilità progettuali e soluzione costruttive sperimentate", Raffaello Borghi et alii, Milano 2008.

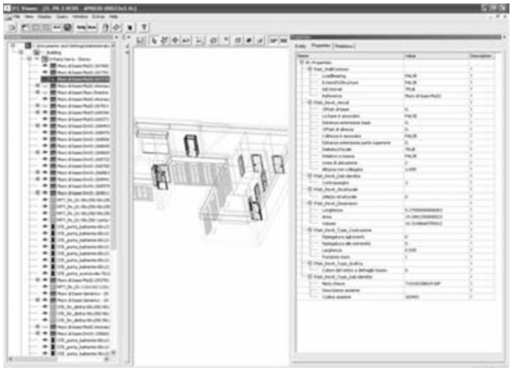

Figure 11. The company's residential building converted into IFC and visualized.

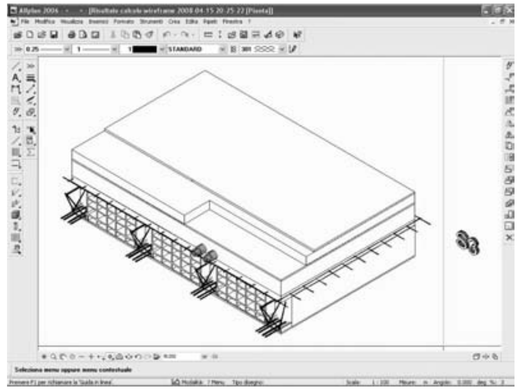

Figure 12. The floor S2 . ifc converted file imported in a CAAD software environment.

imported into C.A.A.D. environments as interoperable character's evidence. These models' representations are published in form of a Compact Disk, authoring by ProTeA research Unit [3], associated with the above mentioned book.

The approach chosen to describe and analyze the thermal and acoustical behavior of the eighteen exemplary parts of work (fourteen solutions for building envelopes, four floors packages) highlights the performance characters and the resulting values at the minimum level of granularity available: the level of every single functional layer, like specific types of plaster, insulation boards, air cavity, brick-laid wall, exterior cladding, etc.

The very objective of this choice of classification consisting in the major support offered to technology innovation issues. I.e. by encouraging the search of the most appropriate solutions to each design case, pursued by original association of materials and components, instead of a rigidly fixed repository of a number of recognized Norms-compliant solutions, of which the eighteen exemplary cases presented are only progenitor "head of families".

The building parts of work modeling was originally executed by a CAAD 3D, Object Oriented, Parametric, IFC- interoperable software, that enabled the separate and specific modeling of each of the material layers inherent the wall or floor package into a thin detail scale: objective is the maximum definition of the parts of work, aimed at associating with each and every one of the compounded layer-objects a Norm –compliant codification and the related attributes, supporting their performance simulation.

[3] "Unità di Ricerca ProTeA – Progettazione Tecnologica Assistita: Prof. Ezio Arlati, con Elena Bogani, Emanuele Naboni Luca Roberti, Sandro Scansani, Sergio Tarantino, Marco Torri, Paolo Valera.

7.1 *Modeling building parts of work into details*

The representation of the Building parts of work in form of BIM has been pursued with the research of the maximum of precision available for the details, in order to demonstrate the ability of the whole repository to match the requirements of a real professional & business employment, facing the refined levels of query for highly qualified performances in connection with building-construction process conscious motivations and economical benefits evaluations. Thence the exemplary BIM objects included in the BIM – IFC Parametric Components Library report the whole data sets supplied by Assimpredil-Ance, also by attaching the performance matrix reporting the CNR – ITC results of the laboratory tests, i.e. the thermal and acoustical behavior related to each of the compounding materials.

Each of the eighteen Building parts of work are named after a conventional commodity category, connoted with the exact designation of the compounding layers and related materials, their dimensions, their appearance character like colors and patterns. The necessity of demonstrating the potential refinement level of the modeling system connected to the reporting of data sets connected to each and every one of the elements, has suggested to disaggregate the individual layers belonging to the same parts of work in its absolutely elementary components, like the hollow bricks and their mortar joints of the same wall.

7.2 *Forwarding an "Augmented Reality" for the .IFC Library*

The association of the attributes' data sets to the BIM objects stored in the Library is made effective by the assignment, retrieval, selection of the functions that are implemented, enabling these operations for the Library's .ifc format files.

The awaited result is made actual: the possibility of establishing the required level of granularity for the designation of Building parts of work based on their compounding layers, enabling the selection of comparable technological alternatives solutions by performances and characteristics described in the form of BIM – IFC objects, structured in a model server library.

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New demands in construction – a stakeholder requirement analysis

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ABSTRACT: Although construction – and its significant impact on quality of life – has received considerable attention in recent years, there is little agreement on how to create an environment that will allow construction to move from a supply-driven industry to a demand-driven industry focusing on delivering extra value (sustainability, productivity and flexibility). Within this context, the Industrialised, Integrated and Intelligent Construction (I3CON) project aims to enable this transformation by using industrial production technologies, integrated processes and intelligent building systems. One key task of the I3CON project is to identify stakeholder requirements – what do clients, designers, contractors, occupiers and communities want from future buildings? These findings will be translated into metrics against which to measure the success of the I3CON project. In this paper the state-of-the-art stakeholder requirements from European countries are presented. A requirement development process has been developed. Key areas have been identified through data analysis of the collected requirements, which the ongoing work within the I3CON project will address.

1 INTRODUCTION

The construction industry is the largest single industry in Europe: It accounts for 10.4% of gross domestic product and more than 50% of gross fixed capital formation. It is also a major employer, with 2.7 million companies and 26 million direct and indirect employees (CIE 2008). The construction industry in the European Union (EU) is facing a plethora of challenges including fierce competition from other regions of the world. It has been recognised that vitality and development in the areas of innovative industrial production technologies, new integrated processes and advanced intelligent building systems are critical to the future of the European construction industry (CITB 2002). Although construction – and its significant impact on quality of life – has received considerable attention in recent years, there is little agreement on how to create an environment that will allow construction to move from a supply-driven industry to a demand-driven industry focusing on delivering extra value (sustainability, productivity, comfort and flexibility). This is particularly true of the construction sector in the EU, which has an extremely diverse industry composed of architects, contractors, consultants, and material and product suppliers. This diversity has resulted in isolated components, services and systems within this sector (Coll 2003). Moreover, the sector has a tendency to focus on technical developments (supply-driven) rather than on what is actually needed (demand-driven).

During the past decade, the building industry has adapted slowly to new technologies and processes compared to other industry sectors like manufacturing. Thus, emerging national and international initiatives emphasise that the construction industry is challenged not only to provide a set of physical outputs, but also to offer the most effective long-term support services to its clients and, at the same time, to respond to society's growing requirements for sustainability, productivity, comfort and flexibility (ManuBuild 2005). This creates a new perspective that requires a radical change in thinking towards an innovative and competitive industry.

In order to address this radical transformation from the current "craft and resource based construction" towards industrialised, integrated and intelligent construction, revolutionary construction and production technologies are needed. These will need to deliver flexible and adaptable building space that uses fewer resources and provides an optimum environment for occupants, improving their quality of life and productivity. They are regarded as the key drivers for change and improvement of the construction industry in the future.

This paper investigates the state-of-the-art stakeholder requirements from European countries in the construction sector on an industrialised, integrated and intelligent construction concept and derives the key requirements using a requirement development approach for life cycle costing, energy management, flexibility, building processes, comfort and customer orientation. This provides the starting point for the vision/focus of the I3CON project.

2 STAKEHOLDER CLASSIFICATION

A stakeholder network consisting of authorities, end-users, owners, designers, contractors and service providers was identified and established, through a series of workshops and brainstorming sessions. This formed the input body for collecting and structuring the requirements. Based upon this network, a list of stakeholders and their categories were developed which provides good coverage of all stakeholder types:

A. Client – individuals or organisations that initiate the building process/generate the need for a building (e.g. housing associations and private developers).
B. Professional team – individuals or organisations that are involved in the project management, design, planning, insurance, and contractual and financial control of the building process (e.g. architects and engineering designers) (The key difference between these stakeholders and those stakeholders in category C below is that these people do not construct or manufacture building elements).
C. Constructors – companies that are involved in building, testing and commissioning of the building (e.g. utilities companies and manufacturers and suppliers).
D. Occupants – individuals or organisations that use the building (e.g. residents and patients).
E. Occupant support services – individuals or organisations that are responsible for the ongoing maintenance & operation of the building and the functions that take place within it (e.g. waste management and maintenance).
F. Regulatory bodies – organisations that provide and enforce codes and standards. These codes and standards constrain other stakeholders (e.g. environment agency and local authorities).
G. Infrastructure – physical and social infrastructures around the building (e.g. transport links and emergency services).

Kemp et al. (2007a) provided more details about this classification and examples of stakeholders in each of the seven categories. They also included a matrix with stakeholders, building types and phases in the building process (based on the building process protocol) in order to have same terminology when speaking of stakeholder types, building process phases, and building types.

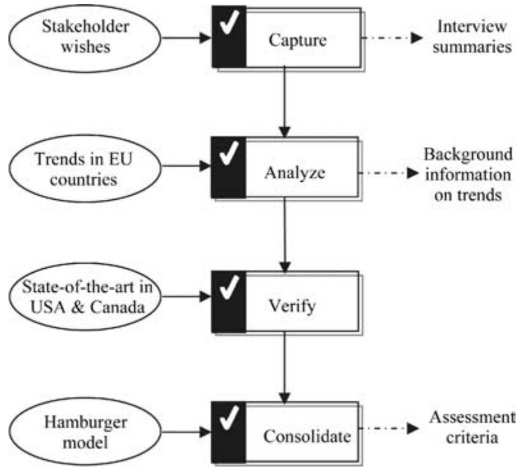

Figure 1. Requirement development process.

The stakeholder requirements were derived from across these stakeholder types, so as to ensure a "common view" on the requirements for innovation in the industry. This has been finalised with feedback received from the project partners involved in various work packages (WPs), together with comments made during group discussion meetings within the I3CON project.

3 THE REQUIREMENT ELICITATION PROCESS

Based upon the above stakeholder classification, a comprehensive requirement elicitation process was created, which comprises a methodology and procedure, requirement collection, and validation and consolidation of requirements. This is summarised and illustrated in Figure 1.

During the definition of the methodology and procedure, a multi-dimensional framework was developed to structure the stakeholder requirements captured in the next step (Kemp et al. 2007a). This consists of four dimensions: European regions, stakeholder categories, building categories and technology subjects (as shown in Fig. 2). The dimensions of building categories, stakeholder categories and European regions are used to provide more insight into the various stakeholder requirements, rather than to limit the stakeholder requirements from some specific domains. For instance, good coverage of European regions is

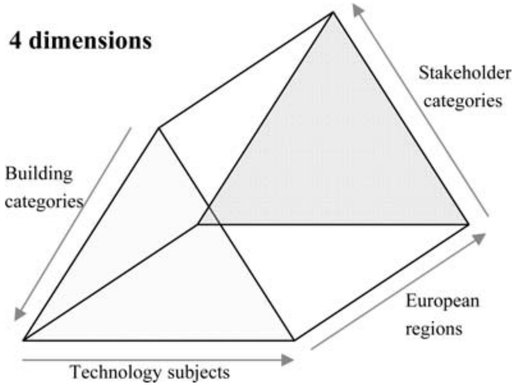

Figure 2. Framework dimensions.

important to avoid capturing requirements relevant to only certain countries. The technology dimension was added so that requirements can be mapped against technical research and solutions delivered by technical WPs within the I3CON project.

In order to obtain high quality, precise and detailed information on stakeholder requirements – rather than large volumes of vague information – it was decided to collect the stakeholder requirements by undertaking formal interviews instead of sending out questionnaire survey. Using interviews to gather the information instead of a questionnaire leads to higher quality information, because the interviewee was able to clarify his/her answers, for instance by giving the context that was underneath a certain answer.

To verify the stakeholder requirements collected in the EU region, the state-of-the-art of stakeholder requirements in other major markets like the USA and Canada were reviewed by the authors through a desktop study (Ye & Hassan 2007). Comparison was made and this confirmed that the ongoing I3CON project is addressing the main and relevant issues in its research technological development (RTD) work.

The Hamburger model (Szigeti et al. 2005) was employed to consolidate the verified requirements. The results from this process were communicated to the relevant I3CON technical WPs, illustrating the relationships between the requirements and the expected impacts and benefits of the relevant technical WPs. This forms the fundamental base for the success of the I3CON project, and will provide assessment criteria to benchmark the outputs of the technical WPs against stakeholder requirements. The identified requirements can be seen as the "program of wishes" from key stakeholders in the European construction industry to achieve innovation of product and process in the building industry. The technical solutions to these requirements are sought in technical WPs within the I3CON project.

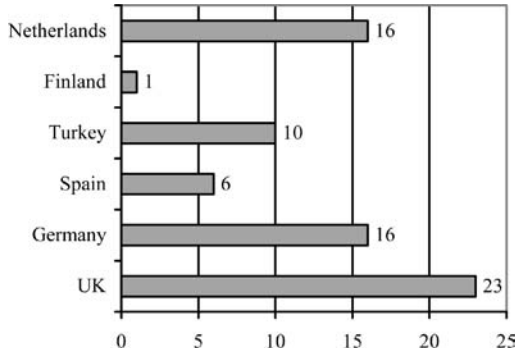

Figure 3. Participants in countries.

4 VOICE OF THE STAKEHOLDER

In order to obtain stakeholders' views regarding the specific features of I3CON, current industry trends and important factors, their main concerns, ideas for possible changes and their requirements and needs, a total of 72 formal interviews were conducted in 6 different countries (Spain, Turkey, the Netherlands, Germany, Finland and the UK), as illustrated in Figure 3. The interviewees were from a range of different roles in building projects, and were classified in categories from A to G, as discussed in Section 2.

The interviews resulted in two types of information, namely the views and opinions of the interviewed stakeholders (qualitative results) and their rating of given factors and trends in the current building industry (quantitative results). This combination of qualitative and quantitative data increases the value of the information collected. The former was obtained by asking open questions during the interviews, to which the interviewees could provide answers and explanations, which provides valuable data, but is more difficult to compare and analyze. The latter (quantitative data) was collected by sending a list of factors and trends to each interviewee beforehand, and asking them to rate the importance of several given factors and trends (subjects in the building industry).

4.1 *Importance of factors*

To prioritise issues in the current building industry, the interviewees were asked to rank the 5 most important factors from a given list of factors, as shown in the left part in Table 1. The identified top 5 factors were: 1. energy reduction, 2. building lifecycle economy & building performance, 3. sustainability, 4. work productivity/comfort and wellness, and 5. flexibility, as shown in the right part in Table 1 (the ranking value is numbered from 1 to 14 where the number "1" stands for the most important factor and the number "14"

Table 1. Important of factors.

Factors	Value
Building lifecycle economy & building performance	2
Capital cost of construction	12
Cost efficiency/reduction during construction	11
Sustainability (in its broadest context)	3
Energy reduction (during operation of the building)	1
Construction methods (i.e. on-site or prefabrication)	10
Construction time	13
Quality of construction (material, etc.)	8
Work productivity/comfort and wellness (end users)	4
Flexibility (e.g. adaptability)	5
Safety	7
Durability	6
Social acceptability	9
Other (not stated above)	14

represents the least important one). Less important factors indicated by the stakeholders included: capital cost of construction, cost efficiency/reduction during construction and construction time, even though these are often the more important factors that project management concentrates on. Based upon these findings, it is clear that most stakeholders now focus more on factors that can deliver extra value (e.g. energy reduction and sustainability) rather than traditional ones (e.g. capital cost of construction and construction time).

4.2 *Importance of trends*

The interviewees were also asked to rate a given list of trends in terms of importance. These trends sit on a more detailed level than the factors discussed in Section 4.1. And they are categorised in six main areas as listed below:

- Economic/financial
- Technological/building process
- Building functionality
- Ecological/environment
- Social/cultural/demographical
- Regulations/political

Each category contained several trends and, for each, the interviewees were asked to select the 3 most important based upon their knowledge and experience. The results from all interviewees are shown in Tables 2–7 (the importance indexes are calculated in percentage based upon the whole data from all interviewees). This data permitted further consolidation of the requirements; the factors and trends identified as very important by all stakeholders are further defined and translated into requirements that map onto the visions and goals in the other technical WPs. For example, "Focus on lifecycle costing" is rated as an important trend by the stakeholders. Linking it to

Table 2. Importance of trends: Economic/financial.

Trends	Index
Focus on life cycle cost	53%
Focus on energy management	40%
Focus on facility management issues	16%
Focus on total cost of ownership	33%
PFI: encourage long-term responsibilities	19%
Increase flexibility & reduce costs	33%
Focus on energy costs	40%
Building as commodity to financial community	2%
Short term vs. long term occupancy	12%
Variation in life span: interior – construction	9%
Other (not stated above)	5%

Table 3. Importance of trends: Technological/building process.

Trends	Index
New building processes (procurement)	31%
New contract models (public private partnership)	36%
Design – simple, clear, puristic style	11%
Design – large windows, a lot of light, high use of glass	0%
Design – combination of materials	4%
Design – high quality materials	20%
Reconstruction, modernisation of old buildings	31%
Refurbishment	13%
Move to modular housing – low cost units & higher quality	20%
Increasing amount of high-rise buildings – improving safety & security	9%
Increasing amount of high-rise buildings – central management system	2%
Innovative housing – domotica	4%
Increasing automation (e.g. intelligent buildings)	27%
Industrialised construction	22%
Applying ICT in construction process	18%
Other (not stated above)	0%

WP2 – *Performance Based Business Models* can lead to the requirement that the business model that is developed, is life cycle oriented. Linking it to WP4 - *New Components and Production Methods* can lead to the requirement that life cycle costs of components should be low.

4.3 *Main findings from open questions*

The holistic questionnaire used in the formal interview consisted of a standard set of open questions that covered the six main categories described in Section 4.2. In this way more valuable/qualitative knowledge and information has been captured than possible using closed questions. Interview summaries sorted by countries were produced by the I3CON partners involved in

Table 4. Importance of trends: Building functionality.

Trends	Index
Impact of flexible working on required housing and office facilities	29%
Multi-purpose/multi-use	36%
New solutions to existing building stock	38%
Residential complexes – including shopping and entertainment centres + recreational facilities	26%
Residential complexes – combination luxury villas and middle scale multi-story apartments	5%
Residential complexes-at a distance from the city centre	7%
Residential complexes – quality & functional design	10%
Residential complexes – security services	7%
Residential complexes – earthquake-proof construction	10%
Flexible buildings to adapt to changes of use	45%
Increasing refurbishment	19%
Increasing demand for flexible/reconfigurable office space	24%

Table 5. Importance of trends: Ecological/environment.

Trends	Index
Focus on climate changes	36%
Changes in living environment – urbanisation increases	10%
Changes in living environment – higher expectations on wellbeing & hygiene	19%
Changes in living environment – increasing need for better Indoor Air Quality and cooling	17%
Increasing focus on energy efficiency – use the sun	19%
Increasing focus on energy efficiency – use of earth heath	12%
Low-energy buildings	36%
Water management/water supply-grey water	2%
Water management/water supply-reuse of rain water	19%
Expectations for thermal comfort and changes in climate: increased use of A/C in all building types	14%
Move to nuclear generated energy	12%
Need for research and products to deal with higher/ more varied temperatures and climate conditions	17%
More use of brownfield sites	14%
Regulatory and representative organisations as stakeholders	10%
Generation of energy close to where it is used	10%
Other (not stated above)	7%

this task (Kemp et al. 2007b). The main findings from interviews with open questions can be summarised as follows:

Industrialisation

- One of the major trends that will become even more important in the future

Table 6. Importance of trends: Social/cultural/ demographical.

Trends	Index
Increasing sense of insecurity and increasing risk aversion in society	21%
Social added value; optimal focus on the demands and desires in society: e.g. sustainability	69%
Improved knowledge infrastructure	31%
Increasing life span of population – implications for housing requirements (e.g. facilities for elderly)	31%
Increase smaller / single dwellings, small family units, affordable for first time buyers	40%
24-hours economy	31%
Increasing 'care in the community' rather than large institutions	14%
Retail – out of town centres vs. increase in small town/city centre units	14%
Other (not stated above)	5%

Table 7. Importance of trends: Regulations/political.

Trends	Index
Litiguous society – impact on design and management of buildings	33%
EU essential requirements – The Energy Performance Building Directive	71%
EU essential requirements – Indoor Air Quality	31%
EU essential requirements – Fire legislation, safety aspects	17%
Quality standards & Certificates	52%
Specific regulations for educating buildings e.g. insulation, air tightness etc.	29%
Other (not stated above)	5%

- Innovation on the subject of industrialization is important, since the construction process has been the same for over 50 years
- Increase use of prefab/standardised building elements to increase speed
- Will bring cost and time advantages and will increase quality

Integration

- Today's building processes are highly fragmented (from procurement to in-use); there should be more cooperation between organizations involved in building projects
- A global picture of the whole process is missing: building projects became more complex and more specialized, and contain more interfaces (problems arise with coordination and the decision making process)
- Maintenance issues not sufficiently thought through in design

Intelligent buildings

- High performance = intelligent = good environmental performance
- Top measure of building performance = total energy consumption; but most important thing a building can do is to make people in it productive; in terms of costs this far outweighs any other costs
- Necessary to be energy-efficient
- Automation is obligatory at a certain level for low-energy technologies
- Users need to learn how to handle such products (training can be offered); higher level of automation requires higher skilled labour
- Intelligent buildings can also mean intelligent concepts: sustainability, flexibility (facades, building technology, adaptable interior)

Main problems

- Changes are necessary in regulations, mentality, businesses, etc. in order to facilitate innovation
- Lack of flexibility in buildings: not built for specific user needs, then tweaked for specific user needs – leading to sub-optimal performance for all users
- Current procurement: time consuming, complex tendering – wasteful
- While looking to make buildings more sustainable, organizations would be reluctant to use highly innovative technology as it is seen as too risky – unknown on-going costs, reliability, etc.
- Buildings change less quickly than social trends
- Increasing specialization: the complete overview is lost so that cooperation becomes more difficult between specialists (each with their own very narrow focus)
- Tender, approval and decision making processes take too long and require excessive administration
- The industry, and innovation within the industry, is mostly supply-driven
- Requirements are proposed either too late or at the wrong time (ecology, user, flexibility)
- Good management / planning from beginning to end is missing (consider what the important criteria in each construction phase are, and if all important aspects were considered)

Market chances

- Regulation is essential for innovation
- Recently, it has been demonstrated that if you offer better quality in terms of what the Client wants, and you really show the quality, Clients will pay for it. Opportunity is to improve level of service to clients
- A large percentage of building projects are the re-use of old buildings, therefore finding smart solutions for refurbishment is important
- Buildings conceived from design phase to accommodate different uses, keeping in mind flexibility
- Projects to be assigned to the best integral offer, with the best technical, resources and economical offer, and not just the lowest price
- Opportunity: high awareness of environmental issues
- Design from 'cradle to grave'
- A high performance building is one that is used for the maximum hours a day and days in a year; efficient to run and comfortable to work in

5 REQUIREMENT VERIFICATION

The requirement verification process checks the redundancy and inconsistency of stakeholder requirements captured by the I3CON partners. The goal of this process is to produce requirements that are consistent, valid in terms of feasibility and necessity, and are quantifiable and verifiable.

In addition to the European region, stakeholder requirements from other major markets like the USA and Canada were also studied. Additional comparisons to these major markets have been conducted by Ye and Hassan (2007) to ensure that the I3CON project considers the main issues relevant to its three "**I**"s and incorporates them within its programme of RTD work. The three "**I**"s are:

- Innovative **I**ndustrialisation production technologies for the construction sector;
- New **I**ntegrated processes for the construction sector;
- Advanced **I**ntelligent building systems for the construction sector

6 REQUIREMENT CONSOLIDATION

The aim of the requirement consolidation process was to actualise the stakeholder requirements captured by the I3CON partners, provide a basis for understanding, communicating and appropriately linking the different requirements to the corresponding WPs within the I3CON project. In order to get from stakeholder expectations to consolidated requirements, the following three steps were taken:

- Prioritize requirements by importance given to them by interviewees
- Translate stakeholder expectations to requirements
- Link requirements to tasks in technical WPs

6.1 *Requirement priorities*

To prioritise captured requirements discussed in Section 4, the top 5 trends identified in the six main categories were used (Kemp et al. 2008). All requirements were prioritized, according to the importance that the

Table 8. Importance of stakeholder expectations.

Requirements	Requirements
A. Economic/financial	**D. Ecological**
1. Focus on life cycle costing	1. Low-energy buildings
2. Focus on energy costs	2. Focus on climate changes
3. Focus on energy management	3. Increasing focus on energy efficiency
4. Increase flexibility and reduce costs	4. Water management – reuse of rain water
5. Focus on total cost of ownership	5. Changes in living environment–higher expectations on well-being & hygiene
B. Technological/Building process	**E. Social/Cultural/Demographical**
1. New contract models	1. Social added value; optimal focus on demands & desires in society
2. New building processes	2. Increase smaller/single dwellings
3. Reconstruction, modernisation of old buildings	3. Improved knowledge infrastructure
4. Increasing automation	4. Increasing life-span of population–implications for housing requirements
5. Industrialised construction	5. 24-hours economy
C. Building Functionality	**F. Regulations/Political**
1. Flexible buildings to adapt to future changes of use	1. Changes in the legislation – the Energy Performance Building Directive
2. New solutions to existing building stock	2. Quality standards & Certificates
3. Multi-purpose/ multi-use	3. Litigious society – impact on design and management of buildings
4. Impact of flexible working on housing & office facilities	4. Changes in the legislation – Indoor Air Quality
5. Residential complexes – incl. shopping, entertainment and recreational	5. Specific regulations for educational buildings

stakeholders gave to them. They highlighted the most important and relevant subjects relating to the vision and focus of the I3CON project.

From the results discussed in Section 4.2, a list of the most important trends per category – in the opinion of the interviewees (all countries and all stakeholder types) – is given in Table 8. The stakeholder expectations are listed in order of importance, starting with the most important per category.

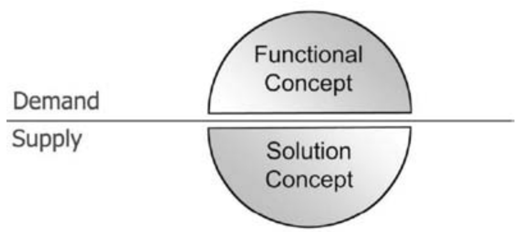

Figure 4. The Hamburger model (Szigeti et al. 2005).

6.2 *Translating stakeholder expectations to requirements*

The next step taken was to translate the stakeholder expectations, which can be described as 'functional wishes', to technical requirements, which the tasks in I3CON technical WPs will address. The 'Hamburger Model' approach (Szigeti et al. 2005) was applied to affect these translations.

This model distinguishes a 'Functional Concept' on the demand side and 'Solution Concepts' on the supply side (see Fig. 4). In other words, the 'Functional Concept' states in 'user language' WHAT is required and WHY it is required and the 'Solution Concept' states in terms of technical specifications HOW the requirements are supposed to be met.

The 'Functional Concept' in the I3CON project represents the stakeholder expectations (captured through interviews in the European countries), and the 'Solution Concept' consists of solutions to the 'functional needs' (to be developed by the I3CON project). Finally the 'Solution Concept' should comply with the 'Functional Concept'.

The performance approach offers a solution using 'performance language' (Pham et al. 2006) as an intermediate step between functional needs and requirements and technical solutions (see Fig. 5). On the demand side, functional needs are translated into performance requirements. These are facility or product related requirements, expressing what properties the built facility should have to facilitate the intended use. On the supply side the technical specifications are translated into performance specifications, expressing

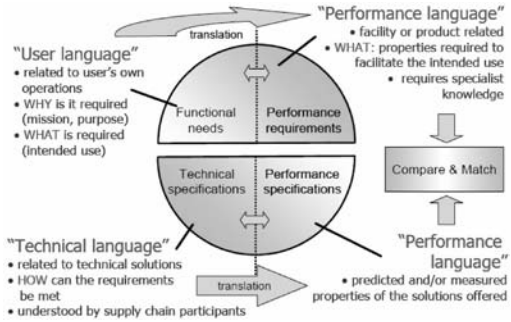

Figure 5. The performance language.

the measured or predicted properties of the offered solution.

Once both the Functional and the Solution Concepts are translated into 'performance language' (assessment criteria), a comparison between demand and supply can take place. For example, the assessment criteria "Flexible buildings to adapt to future changes of use" is translated into the different 'languages' as shown in the example below:

- Functional needs: the end user of an office building wants to be able to make more work places available when the number of employees increases. They want flexibility in the use, to adapt to future changes.
- Performance requirements: in the design of the office buildings, meeting rooms (4 persons) have the same dimensions as a (closed) office for 2 desks.
- Technical specifications: standard dimensions are used, e.g. 3.6 metre × 3.6 metre for the meeting room/ closed office space.
- Performance specifications: by only changing the interior (furniture), the space is easily adaptable to the growth in number of employees.
- The comparison/matching between Functional and Solution concepts is part of the peer review work in the I3CON project, which checks the quality of the outcome in relevant WPs in relation to stakeholders' requirements.

Finally, the stakeholder requirements identified based upon the authors' research work are combined and summarised in six main themes, as shown in Table 9. This can be seen as new demand information and the vision/focus of the I3CON project according to different stakeholders.

6.3 *Linking requirements to technical tasks*

After the most important stakeholder expectations were identified, they were linked to the other work packages in the I3CON project to which they apply, e.g. the expectation of stakeholders to develop new contract models applies to WP2- *Performance Based Business Models* in which new business models are researched. A matrix mapping approach was used to create the links between requirements and tasks. Kemp et al. (2008) provided a more detailed description of this approach, and the main results of identification of the links and the selection of the 5 most important requirements for the technical WPs within the I3CON project.

Table 9. Stakeholder requirements in six main themes.

Life cycle costing
• Total cost of ownership
Energy management
• Reduce energy costs
• Low-energy building
• Energy-efficiency
• Water management
• EU requirement: Energy Performance Building Directive
Flexibility
• Reconstruction, modernisation of old buildings
• New solutions to existing building stock
• Adaptable buildings for future changes of use
• Multi-purpose/multi-use
• Impact of flexible working on housing and office facilities
Building process
• New contract models
• Industrialisation
• Integration (processes)
Comfort
• Changes in living environment: higher expectations in wellbeing and hygiene
• EU requirements: Indoor Air Quality
• Specific regulation for educational buildings: insulation, air tightness, etc.
• Intelligent building
Customer orientation
• Increase smaller/ single dwellings: small affordable family units
• Increasing life span of population: implications for housing requirements
• 24-hours economy

7 CONCLUSIONS

In this paper, the authors addressed the state-of-the-art stakeholder requirements from European countries in the construction sector. A requirement development process was developed, which comprises methodology and procedure, requirement collection, validation and consolidation of requirements. Several key areas have been identified through the data analysis of the collected requirements, which the main RTD work within the I3CON project will address. This has been achieved by creating a linkage between the main findings and all technical tasks through a matrix mapping approach. This led to a fundamental base for creating new construction demands for future buildings on which the I3CON project will focus.

Future work will focus on using new metrics generated from these findings to further guide the ongoing RTD work in the I3CON project.

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IFC Certification process and data exchange problems

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ABSTRACT: The interest in using Building Information Models (BIM) as a central design and information management media in construction projects is rapidly increasing around the world. Examples of this phenomenon are several national efforts, BIM requirements of owners and clients or even legal requirements to deliver BIM in public projects. In addition, several private companies have more or less successfully started to deploy BIM in their internal processes and supply chains. This situation has created an emerging need for model-based data exchange between different applications in everyday projects and changed radically the need for IFC compliant applications. Until 2007 only few real projects used IFC data exchange and most of these cases were more or less research or pilot projects. In such projects it is possible to include special technical expertise into the team, and also the tolerance for technical problems is much higher since all participants know that the project is trying to push the existing limits. In normal construction projects it is not possible to use specialized BIM experts; the data exchange must be relatively smooth and trouble-free since people cannot test technology in their daily work. However, everyone who has tested IFC-based data exchange in real projects knows that it still has major problems.

To investigate reasons for the quality problems of the IFC certification and to some extent the quality problems of IFC support in certified software products the author analyzed the latest IFC 2x3 certification documentation in autumn 2007 and distributed a draft paper in IAI for comments. The draft paper generated an active discussion and most of the identified problems were recognized in the IAI community. In addition, the author received some additional information which clarified the problems. This paper documents the main findings of the analysis and proposes some crucial improvements to overcome the problems in the IFC certification process.

1 INTRODUCTION

The interest in using Building Information Models (BIM) as a central design and information management media in construction projects is rapidly increasing around the world. Examples of this phenomenon are several national efforts – such as National BIM Standard in USA (NBIMS 2008), buildingSMART in Norway (NO 2008), CRC Construction Innovation in Australia (CRC CI 2008) – and BIM requirements of owners and clients – such as GSA in USA (GSA 2008), Senate Properties in Finland (Senate 2007), Statsbygg in Norway (Statsbygg 2007) – or even legal requirements to deliver BIM in public projects which are implemented in Denmark (DK 2008). In addition, several private companies have more or less successfully started to deploy BIM in their internal processes and supply chains.

The current situation in the industry has created an emerging need for model-based data exchange between different applications in everyday projects and changed radically the need for IFC (IFC 2008) compliant applications. Until 2007 only few real projects used IFC data exchange and in most of these cases were more or less research or pilot projects (Kiviniemi et al 2008). In such projects it is possible to include special technical expertise into the team, and also the tolerance for technical problems is much higher since all participants know that the project is trying to push the existing limits. In normal construction projects it is not possible to use specialized BIM experts; the data exchange must be relatively smooth and trouble-free since people cannot test technology in their daily work. However, everyone who has tested IFC-based data exchange in real projects knows that it still has major problems, even if all the software products have IFC certification.

To investigate reasons for the quality problems of the IFC certification and to some extent the quality problems of IFC support in certified software products the author analyzed the latest IFC 2x3 certification documentation (IFC Certification 2007) in autumn 2007 and distributed a draft paper in IAI for comments. The draft paper generated an active discussion and most of the identified problems were recognized in the IAI community. In addition, the author received some additional information which clarified the problems. This paper documents the main findings of the analysis

Table 1. Documented IFC 2x3 certified software products.

Application	Release	Vendor	1st step	2nd step	Comment
Active3D	v 4.0	Archimen	06/2006	03/2007	Import only
Allplan	2066.2, 2008	Nemetschek	06/2006	03/2007	
ArchiCAD	11	Graphisoft/Nemetschek	06/2006	03/2007	
Bentley Architecture	8.9.3	Bentley	06/2006	03/2007	
Revit Architecture	6.4	Autodesk	06/2006	03/2007	
Solibri Model Checker		Solibri	06/2006	03/2007	
TEKLA Structures	13	TEKLA	06/2006	03/2007	Import only no 2D
AutoCAD Architecture	2008	Autodesk	11/2006	03/2007	No 2D
House Partner	6.4	DDS	03/2007	03/2007	

Table 2. Test case distribution by the exporting software application.

	Allplan	Archi CAD	AutoCAD Arch.	Bentely Arch.	Revit Arch.	SCIA	Tekla	Other	In total
Spaces	2	1	2	2					**7**
Walls	17	16	12	18	11	1	3	1	**79**
Beams	6	3	3	6	3	4	6	3	**34**
Columns	3	5	3	5	3	4	6	1	**30**
Slabs	3	5	4	3	4	2	3		**24**
Doors	3	2	6		5			2	**18**
Windows	3	2	7	1	2				**15**
Staris	1	1	1	2	1				**6**
Ramps		1	1	3	2				**7**
Railings		1	1	2	1		1		**6**
Roofs	2	3	3	3	1			1	**12**
Curtain walls		2	2	1	1				**6**
Members		1	2	2			2		**8**
Plates		1					3		**4**
Piles		1		1			1		**3**
Footings	1	1		2			1		**5**
In total	**41**	**46**	**47**	**51**	**34**	**11**	**26**	**8**	**264**
Percentage	**16%**	**17%**	**18%**	**19%**	**13%**	**4%**	**10%**	**3%**	**100%**

and proposes some crucial improvements to overcome the problems in the IFC certification process.

2 COMMON OBSERVATIONS OF THE IFC CERTIFICATION DOCUMENTATION

The latest IFC certification process is based on the Extended Coordination View for IFC 2x3. Based on the information on the official IAI ISG (Implementation Support Group) web site at the time of the study 10 applications passed the IFC 2x3 Extended Coordination View Certification; all of them conditionally, requiring that the “remaining issues will be solved in the near future”. However, only 9 applications could be studied since there was no information of one certified application in the documents. Software products mentioned in the certification documents are documented in Table 1.

In practice the certification concentrated into IFC import. There was no systematic testing of IFC export. The only part testing export was the creation of the test files, but since those are different and there are no clear requirements how their structure and content should been defined, it is possible, even likely, that the cases are selected based on the known capabilities of each software and thus may not test any potential problem areas.

The available certification documents did not include information of the property sets. Thus, the question how the support for property sets in different objects is implemented could not be studied.

Another issue was that all test cases were very small independent files representing some individual building element or a small group of such elements. None of the tests handled a whole building. Unfortunately, several tests using earlier IFC versions and larger files indicate that a certification using this testing method does not guarantee the functionalities with real buildings.

The test cases exported by different applications in each category are documented in Table 2. It is noteworthy that some applications are certified for import only and thus not included in this group.

However, when reading this paper it is notable to remember that certification is a complex process; balancing between "*what is acceptable for end-users and economically achievable for vendors. If the certification can only be passed, when no issues are left, there will never be certified applications. As there is no bug-free software available in the world, there will never be bug-free IFC- interfaces. . . . Due to lack of interest in the industry, it is a huge problem to find enough of pilot-users for the IFC-interfaces, especially for cross-testing between the various applications.*" (Steinmann 2007). Thus, passing certification must include the question what an acceptable balance is. In the end, this is not something the people in the testing process can decide, but what the end-users will decide by adopting or discarding the IFC data exchange in their projects.

3 BUILDING ELEMENTS, GENERAL OBSERVATIONS

The total number of valid test cases used in the certification was 264, divided in 16 groups: Spaces (7), Walls (79), Beams (34), Columns (30), Slabs (24), Doors (18), Windows (15), Stairs (6), Ramps (7), Railings (6), Roofs (12), Curtain Walls (6), Members (8), Plates (4), Piles (3) and Footings (5).

The certification results must be interpreted since all details were not recorded in the available documentation. This paper regards the results accepted if the result were marked "OK", "Geometry and connections OK", "Geometry and materials OK" or "Geometry OK" without any major comments i.e. at least model geometry can be exchanged, but based on the available documentation it is not possible to say if some other type of data was missing. Unfortunately there was no specific information what may be missing in the cases, where the marking is something else than simple "OK". The passing criteria were not documented, and since testing is done by several people independently, the criteria can vary significantly between the software applications.

The above interpretation assumed that an empty result was not OK, i.e. a failure. However, the comments of the first draft paper revealed a peculiarity in the testing; the number of cases increased during the process and the first tested applications were tested with fewer cases than the last ones. (Velez 2007) However, since only some of the empty results could be explained by this reason, the interpretation "no result" = "failure" was used also in this paper. Only the names of the software products have been removed from the comparisons since the vague certification documentation makes reliable comparisons of individual applications impossible.

Another strange issue related to the testing material which came up in the draft document was that there were test cases which had errors. Some applications could import these invalid files, but some not. However, it is unreasonable to claim that there is an error in the importing application if it does not accept invalid data (Solihin 2007). These invalid test cases are removed from the results in this paper as well as possible based on the available documentation, which reduces the total number of valid test cases significantly; from 312 to 264, i.e. 16% of the original test cases had errors.

One important aspect is also that some of the test cases represented very common geometry in buildings and some were rather unusual, i.e. not often used in building design. Thus, the statistical approach does not necessarily correlate with the ability of different applications to exchange IFC data in real projects. However, since there was no weighting of the importance of different test cases and the participating implementers have approved all test cases into the certification process, the statistical approach and some additional view points, such as deviation of results, were selected as the methods to evaluate the results.

4 RESULTS BY ELEMENT TYPE

In Figure 1 legend "All OK" means the percentage of test cases which all 9 applications have passed in the certification, "8/9 OK" means the percentage of test cases which at least 8 applications passed in the certification. This is documented to see the impact which just one application's bad results may cause; a typical example of this are spaces where "All OK" is 14%, but "8/9 OK" is 86%. "Average" line indicates the average number of test cases passed in each category (Figure 1).

The results vary significantly. In total 58% of the test cases passed in all applications and 74% in 8 of the 9 applications. Compared to this, the average passing rate of different test cases is relatively good, 89%. In each element category at least some test cases passed in all applications. When looking average results (OK average) the situation looks also relatively good; the results vary between 70% (Windows) and 100% (Piles). However, the results indicate also one major problem: the deviation of test cases passing or failing is very high. If less than 60% of the test cases in all element categories pass in all applications, it means that the end-users cannot rely on the IFC exchange of the certified applications.

Unfortunately, the results in some element categories are even worse because only very few test cases in these problem categories pass in all applications: spaces (14%), doors (17%) and windows (20%). The deviation in these classes is very high, i.e. different

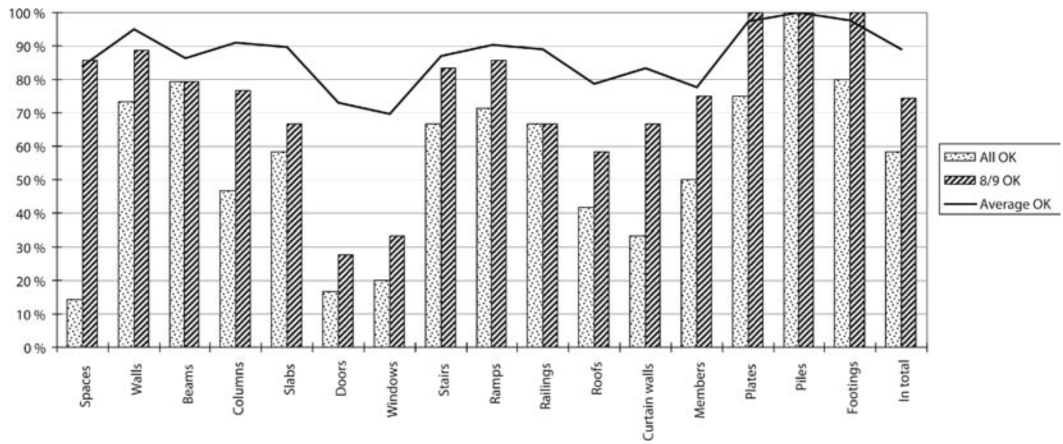

Figure 1. Results by the element type.

Windows	App.1	App.2	App.3	App.4	App.5	App.6	App.7	App.8	App.9
Test 1	–	+	–	+	–	+	–	–	–
Test 3	+	+	+	+	+	–	+	–	–
Test 4	+	+	+	+	+	–	+	–	–
Test 5	+	+	+	+	+	+	+	+	+
Test 6	+	+	+	+	+	+	+	+	+
Test 7	+	+	+	+	+	+	+	+	+
Test 8	+	+	+	+	+	–	+	–	–
Test 9	+	+	+	+	+	–	+	–	–
Test 11	+	+	+	+	+	+	+	–	+
Test 12	–	+	+	+	+	+	–	–	+
Test 14	+	+	+	+	+	–	+	–	–
Test 16	–	+	–	+	–	+	–	–	+
Test 17	+	+	–	+	–	–	–	–	–
Test 18	+	+	+	+	+	+	–	+	+
Test 19	+	+	+	+	+	–	–	–	–

Figure 2. Test case deviation example + = pass, – = no.

cases pass in different applications and it is very difficult to guess in which cases the space, door and window data can be exchanged without some missing or misrepresented information. For example, in windows only 3 test cases (5, 6 and 7) pass in all application (Figure 2). This situation makes the data exchange in real projects extremely demanding, if not impossible, depending on the software combination and object types used in the project.

5 RESULTS BY SOFTWARE

After the first version of the discussion paper was published in the IAI community, several representatives of software vendors notified about mistakes and shortcomings in the certification documentation. Based on these comments, it is obvious that the official documentation was incomplete and contained several errors, thus the results of this study cannot be used to judge the quality of IFC exchange of any individual product. However, the issues in the study were the insufficient quality of the certification process and the potential unpredictability of the IFC data exchange following from the inadequate certification process. In that sense, the incomplete official documentation confirmed the problems which were the hypothesis of this study.

When looking how well different applications have passed the test in average (Figure 3), four of the applications are clearly above 90%; applications #1 and #2 97%, #3 95%, and #4 93%. In addition, none of the average results are bad compared to the results of earlier certification workshops; the lowest passing rate is now 81% (application #9). This indicates clearly that the certification process consisting of several steps and workshops has improved the quality of IFC interfaces, although not yet sufficiently. The problem is not the average level, but the deviation in the results, i.e. unpredictable results when exchanging data between applications.

The average passing level correlates strongly with deviation of the results in each element category; the four best applications have high passing rates in all categories (lowest rate 75–80%). In the applications with the average passing rate below 86% the deviation increases (lowest rate 27–47%).

However, as stated earlier, the certification results with small test cases do not necessarily correlate with the software's ability to exchange IFC data in real projects.

6 PROBLEMS AND SHORT-COMINGS IN THE CURRENT CERTIFICATION

The basic conclusion of the results is that there are several problems and short-comings in the IFC 2x3 certification process.

1) The certification results are not documented in a manner that would help the end-users to understand the potential or limitations of the IFC support in and between different products. This is a crucial

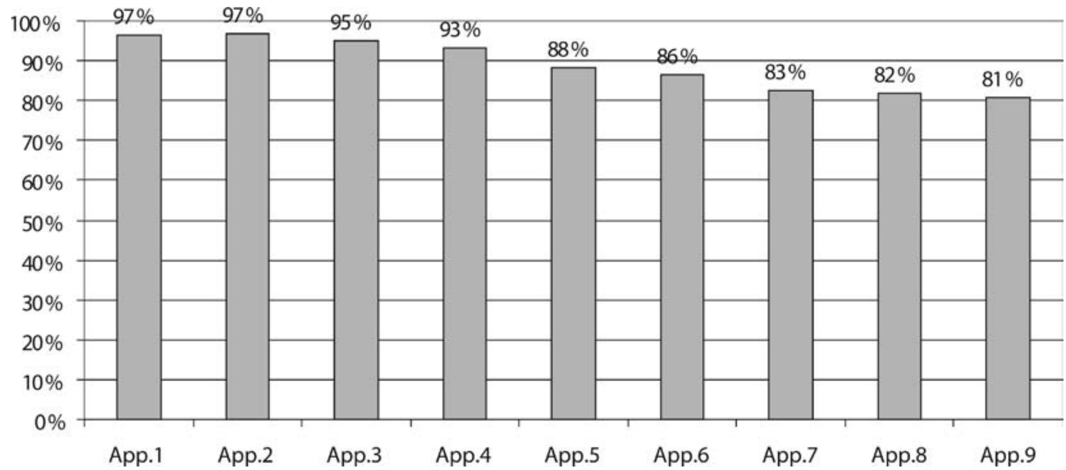

Figure 3. Average passing rate of the IFC 2x3 certified applications.

issue for deployment of IFCs. If the end-users do not know what can be exchanged reliably with IFCs, they cannot start using it in real projects, or at least the use requires significant testing effort and high technical knowledge about IFC-based data exchange.

2) Even the documented results are ambiguous. Based on the comments of a participant in the 3rd certification workshop: "*Each application was tested by one person who administered the testing of all test cases for that application. There was no documentation available for the testers about what exactly should be tested by each test case, what outcome is acceptable and how results should be documented. During the certification there was some discussion among the testers about what to test and how to report. However, for the statistical analysis the possibility for different interpretations of the test cases pose a problem; what if one tester was simply stricter than the other testers, or used different type of 'language' than the other testers when reporting the results?*" (Hietanen 2007). To correct this, the certification process should be changed so that each tester would test all applications with a certain test case and document the results coherently. In addition, the exact procedure what to test and the criteria what is acceptable should be agreed and documented thoroughly in advance. This could also help to identify the deviation problem by identifying clearly the cases which are problems for several applications.

3) There is no systematic testing of IFC export; the only part of the certification process testing the export capabilities was the creation of test cases, but those were more or less arbitrary and the exact content is not standardized, only some basic outline such as: "*export various possibilities to use the material layer set*". The export capabilities should be tested and documented systematically if an application is certified for export.

4) Based on the certification documents, it seems that the semantics of the imported building elements is not tested, only that the geometry seemed to be correct. This means that a building element may not be the same as the original after the IFC export-import procedure, or that its measures or location can be different, because only some of the test cases included checking mechanisms for this aspect (Hietanen 2007). The observation of measure and location errors in IFC exchange is also supported by a recent interview in Denmark (Graabaek 2007), although this interview does not clearly indicate which IFC version has been used. In addition, if the object classes are not mapped correctly between the IFCs and application's internal structure, it can cause severe limitations in the usefulness of the objects after import. Geometry that seems to be correct is not sufficient for the use of BIM in most cases.

5) The exchanged content, for example property sets, are not documented in detail. Thus, it is impossible to say if the attributes are properly exchanged or not. All information which is part of the certification should be documented in detail in the results.

6) As mentioned above software products which joined the process early are tested with fewer test cases than the ones joining later and thus have no results in the new cases. This means that the testing process is inconsistent and it is impossible to say if the application would pass the new cases or not. The set of test cases should not be modified during the process or, if there is a valid reason to add new

cases, all applications should be tested with those too, since adding new cases which test nothing new does not make sense.

7 CONCLUSIONS OF IFC 2X3 SUPPORT FOR SPACES AND BUILDING ELEMENTS

Based on the available certification data it seems that the IFC 2x3 data exchange is still limited mainly to simple building geometry including some additional information, basically more or less "standard buildings". Immediately when the geometry gets complicated and includes use of clipping planes or complex voids, the reliability of the IFC data exchange suffers significantly. In addition, even basic elements such as spaces, doors and windows can cause severe problems.

Although most simple building elements are relatively well supported in most applications, there are only very few test cases which passed without problems in all tested applications. This means that the IFC exchange is not reliable in practice and there is always a risk of missing or incorrect information when exchanging information in IFC 2x3 format, unless the specific applications used in a project have been tested with the required data content. This conclusion is also supported by the observations of real end-users in real projects (Graabaek 2007).

In addition, the certification process does not really test the IFC export capabilities of the certified software, which significantly increases the potential risks and problems of using IFC exchange. In possible problem situations it can be difficult to identify if the problems are caused by the sending or receiving application.

The main purpose of this study was to help in the discussions of the development of the certification process by identifying some of its shortcomings and potential problem areas and by raising the question what are acceptable amounts and types of failures in certified applications. These are crucial question for IAI now when the use of IFC exchange is rapidly growing in real projects. There is a danger that AEC/FM industry may abandon the IFC exchange if the failure rate will be too high and the exchanged data cannot be trusted.

However, it is important to emphasize that the certification of all applications was conditional. The final quality of the certified IFC 2x3 compatible software can be judged only after the shipping products are publicly available and possible corrections have been made. In addition, the first version of this paper published in autumn 2007 already raised the discussion of the certification quality in the IAI and started the development of a new process which will correct the identified problems. A crucial question is also the funding of the certification process; creating a robust certification process, test cases and running the tests is an expensive effort and possible only if the industry is willing to fund it.

ACKNOWLEDGEMENTS

My special thanks to Thomas Liebich, Rasso Steinmann, Jiri Hietanen, Wawan Solihin and Angel Velez for the certification material and their comments about the certification process and its difficulties. The purpose of this study is not to criticize the creditable and committed work in the development and implementation of IFC, but to help to convince the AEC/FM and software industry that providing funding to establish a robust and reliable certification process is an absolute necessity for the deployment of interoperability into industry processes.

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Semantic intelligent contents, best practices and industrial cases

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A strategic knowledge transfer from research projects in the field of tunneling

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ABSTRACT: The purpose of this paper is to describe a system (GAC- Active Knowledge Management) to transfer knowledge from research projects to society. This paper approaches the problem of knowledge transfer from a case study angle. The system is implemented in "The multidimensional city" which is a multi-disciplinary research project that promotes the development and implementation of Spanish technological innovation in underground construction. The objective of the GAC case study is to create a methodology to store and retrieve knowledge and act as a starting point of generating knowledge. The GAC project aims at achieving full integration of large set of contents created in research projects related to subterraneous sites. Then, the project has developed several types of metadata for tagging contents: traditional content metadata, context metadata, usage related metadata and metadata acquired through social interaction. Once the project is finished, users and interested parties should not only search information but also update the system, enriching it.

1 INTRODUCTION

It can be perceived that the different knowledge transfers that exist between the academic institution and industry throughout the development and delivery of the cross sector collaborative research project hold different bearing on its achievements.

These include the successful transfer of knowledge from research projects to society and companies who will benefit from research.

During a research project the channels of transferring innovation include basically explicit knowledge and sometimes it is just formalized in text document such as deliverables that at the end they are forgotten.

The traditional knowledge transfer from research projects are journal articles or conferences but the time spent from the generation of the knowledge to the publication of the paper can take at least one year. Moreover, when accessing knowledge by journal articles, information is basically classified by keywords, article title and author. With such a restricted retrieval of information the access of this information becomes tough and difficult.

Moreover, research projects usually have their own web page with information of the project and a private area to share documents and information related to the project. Normally, this information is not well organised and once the project has finished the information is lost, there is no search engine to make the research findings reusable.

Recently, academics and industries are starting to pay attention to knowledge transfer and more specific to tacit transfers which is the most difficult knowledge to manage. It is perceived that collaborative research initiative to industry may impact positively more than tangible means.

2 BACKGROUND

2.1 *Tacit and explicit knowledge*

Knowledge is a complex concept but the only consensus seems to be the notion that knowledge is more than just mere data and information. Data can be considered as the basis for creating information and knowledge. "Data is a set of discrete, objective facts about events" (Davenport and Prusak, 1998). Data can be produced, codified, and distributed without a reference to the context or person.

In contrast, information refers to a context. Information can be considered as messages or news created by the interpretation of data. This information can be understood by the recipient and has meaning to the recipient.

Then, knowledge comes from the processing of the perceived information and contextualization of a person. Knowledge can only exist in the context of person and his beliefs and experience. "Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information" (Davenport and Prusak, 1998).

There are two types of knowledge: tacit and explicit knowledge:

- Tacit knowledge is the personal and context-specific knowledge of a person. It is bound to the person and is thus difficult to formalize and communicate. Consequently, it is not possible to separate, store, and distribute the whole knowledge of somebody.
- Explicit knowledge in contrast can be codified, collected, stored, and disseminated. It is not bound to a person and has primarily the character of data.

2.2 *Knowledge management*

Knowledge is quickly becoming the prime source of wealth in the world, not only for corporations and individuals but also for nations and societies.

There are different knowledge sources. From one hand, knowledge can come from companies' individuals' experience. But from the other side, and probably the most important knowledge in terms of competition and innovation, knowledge comes from research projects. Therefore, knowledge management is the most appreciated value in companies.

It is argued that knowledge management is a necessity due to changes in the environment such as increasing globalization of competition, speed of information and knowledge aging, dynamics of both product and process innovations, and competition through buyer markets. Knowledge management promises to help companies to be faster, more efficient, or more innovative than the competition.

Also, the term "management" implies that knowledge management deals with the interactions between the organization and the environment and the ability of the organization to react and act.

Two different knowledge management strategies can be perceived:

- the codification strategy has the objective to collect knowledge, store it in databases, and provide the available knowledge in an explicit and codified form. Such a reuse of explicit knowledge and solutions can save time and money. The design of databases, document management, and workflow management can be considered to be part of this strategy.
- the personalization strategy has the objective to help people communicate and exchange their knowledge using Information Technologies or only by face to face meetings.

2.3 *Research knowledge transfer*

It is well known that knowledge is generally difficult to transfer. There are countless examples of sound research projects never making it to the practice community, and of organizations in need of solutions typically ignoring academic research findings in developing management strategies and practices.

There is a problem in the research: "as our research methods and techniques have become more sophisticated, they have also become increasingly less useful for solving the practical problems that members of organizations face".

There is a large gap between academic research and practitioners and can be found in nearly all disciplines. Beyer and Trice (1982) conducted a literature review on research utilization and concluded that the: "most persistent observation . . . is that researchers and users belong to separate communities with very different values and ideologies and that these differences impede utilization".

In recent years many research studies analysed the knowledge transfer (Serban and Luan's 2002; Simmonds et al., 2001; Cavusgil et al., 2003; Dayasindhu, 2002; Büchel and Raub, 2002; among others). But the task of transferring knowledge successfully is far from straightforward.

Traditionally, knowledge transfer is viewed as information that could be passed on mechanistically from the creator to a translator who would adapt it in order to transmit the information to the user. These classical models implied a hierarchical top-down relationship between the generator of knowledge who holds the resource (knowledge) and the user (receptacle).

To avoid this problem, the latest models to transfer knowledge from the research to practice communities are the communities-of-practice and the knowledge network model.

- The communities-of-practice are "groups of people informally bound together by shared expertise and passion for a joint enterprise" (Wenger and Snyder, 2000). Communities of practice are not mandated, but they can be encouraged, supported and promoted. They are generally motivated by people realizing that they could benefit by sharing knowledge, insights and experiences with others with similar goals; they typically form around best practices or common pursuits. Because communities of practice generally focus on informal, voluntary gatherings of individuals based on shared interests, they are sometimes seen by organizations as "unmanageable" endeavours.
- Knowledge networks, on the other hand, which have more organizational support, are believed to contribute directly to the bottom line.

Concretely, in the construction sector, The European Construction Technology Platform (ECTP) is the European community of practice. Its objectives are to:

- Arrange discussion forums, workshops, etc.
- Formulate visions and strategies
- Report to the Support Group

– Disseminate all deliverables
– Encourage and support proposals for projects and Joint European Technology Initiatives.

All European countries have their own national platform. In Spain, the construction platform is called Plataforma Tecnológica Española de Construcción (PTEC) and it is dedicated to promote innovation in the field of construction with the final goal to assure better efficacy in taking profit of the investigation and research inversions in construction. These communities of practices include all stakeholders in the construction sector and are industrially driven.

2.4 *The multidimenisonal city*

The multidimenisonal city is a Spanish strategic scientific-technological project from the Ministerio de Educación y Ciencia PSE 10-2005. It is a multidisciplinary research project that promotes the development and implementation of Spanish technological innovation in underground construction.

The multidimensional city is a Project endorsed by the "Plataforma Tecnológica Española de Construcción – Hacia el 2030: Innovación y cambio eficiente del Sector de la Construcción". It focuses on five strategic lines: underground construction, Cities and buildings, Safety and Health, Sustainable construction and cultural heritage, promoting an efficiency improvement of the productivity and safety and a significant reduce of environmental impacts.

The project's partners integrate not only the on-the-field engineering experience and technical know-how of the industry, but also the research capabilities and conceptual innovation of the academic sector.

The multidimensional city is fully committed to contributing to an increased quality of life by reducing construction time and cost of planned and future underground infrastructures.

3 RESEARCH APPROACH

Currently, there are thousands of research projects running. The majority have a web page for the society to know about the project and an intranet for the partners to exchange documentation, planning and information. Once the project has finished, this information still remains in the web but it easily becomes old because nobody updates it. Moreover, normally the information is disorganised and difficult to retrieve.

Owing to the fact that each project is different, it's very difficult to organise and transfer knowledge using a standardised tool.

This paper presents a tool developed to transfer the knowledge generated in a very big national research project. The objective is to create a starting point of generating knowledge and to carry on once the project is finished.

Currently, no common methodology or standards are employed due to the different approaches in knowledge structuring as well as the different content languages. Because of these barriers, the potential impact on the huge user basis of stakeholders is strongly limited.

This paper exposes a standard approach to create an accessible database for research projects to be managed and to improve knowledge transfer.

The steps when defining such a system are:

1. Identification of the knowledge field
2. Identify users
3. Define Use Cases and Scenarios
4. Identify the different types of knowledge or information
5. Knowledge analysis
6. Define a Conceptual Map of subterraneous works (Thesaurus)
7. Define Metadata (LOM)
8. Database creation
9. Define the database
10. Create the enrichment tool
11. Create the search tool
12. Create the access portal

In the GAC three different users are defined. From one side, the project partners will be the first end users. As it is a very big research project in the field of tunneling, many researchers from different centers, companies or universities are working on similar topics. In the first annual meeting, the different partners found that some of them where doing complementary research and sometimes one partner could help the other and they hadn't realized it until they came across the presentations of the other partners. Therefore, the GAC will help all project partners to know what is being done in other sub projects.

Other users will be teachers and students. As GAC will be organized in Information Objects (IO) and many metadata will be implemented in this IO, all the knowledge generated in this project will be used to create a "Tunneling course". Some basic concepts will be also included but the main idea is to incorporate the most innovative solutions from the research.

Finally, once the project is finished, it is aimed that the GAC could act as a community of practice in the field of tunneling and users will be all interested people in this area who will incorporate new knowledge and also find information from previous researches.

The system is based on contents which are made up of information units (IU) which are the basic information objects (IO). An IU is made up of text and iconic objects (pictures, animations, videos).

IO have to fulfill several purposes.

– to be the basis for a consistent content generation by authors/users
– to allow reusability of IO

– to allow for a maximum of flexibility for the dynamic generation of online information

3.1 *Knowledge analysis*

To classify the knowledge coming from "The multidimensional city partner's" the project has developed several types of metadata for tagging contents.

When analyzing the knowledge, the metadata to be incorporated in each IO was defined. With the aim to create an interoperable infrastructure with other possible databases, the system uses as a basis the LOM IEE 1484.12.1 Standard for Learning Object Metadata (IEEE, 2002). This standard was adapted to the project necessities. Therefore, seven types of different metadata were incorporated:

– Content metadata,
– Media metadata,
– Formal aspects metadata,
– Copyright metadata,
– Educative metadata,
– Users' metadata and
– Contextual metadata.

One of the most important metadata is the content metadata, so different classification methods such as thesaurus for underground construction were analyzed (AFTES, 1998, AETOS, 1989, CONNET 2008, ITA, 2005, ISTT, 2005, etc.). From this analysis, none of them fit with the objectives of the project so it was decided to take as a basis the ITA thesaurus adapting it to the project purpose. Figure 1 shows the first levels of classification of the "Content Thesaurus" which will be used in GAC.

Not only content metadata was organized in different classes and subclasses, but also media metadata. It is a fact that in research projects different types of information is used and generated. Therefore an organization of the media by classes and subclasses is necessary.

The other metadata is defined in standard tables containing different types of information.

Technically, metadata is stored in a relational database implemented in PostgresSQL. This database contents 35 tables. The physical support is a Dell Power Edge 1950 server.

3.2 *GAC development*

The tool for incorporating metadata is programmed in PHP with some Javascript functions that allow the metadata introduction in a easy way.

When accessing to the tool (http://lcm-gac.org/lcm) there is a users' validation. The user can upload the IO and insert the metadata fields. 12 from 30 fields are compulsory to allow retrieve the information easily. These metadata is divided in the seven fields that LOM defines (General, Lifecycle, Technical, Educational, Rights, Relation and Classification).

The "Classification" category is based in two thesauruses: the Content thesaurus which classifies the content of the IO and the Media thesaurus which classifies the type of information. Both thesauruses classify the information into three hierarchical categories that will be the basis of the "search tool". These thesauruses

Figure 1. Content thesaurus.

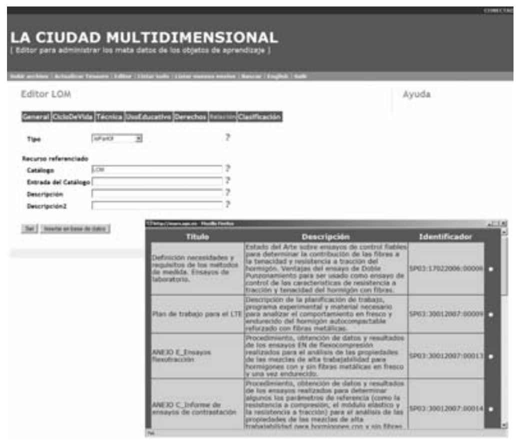

Figure 2. Example of incorporating the "Relation" metadata.

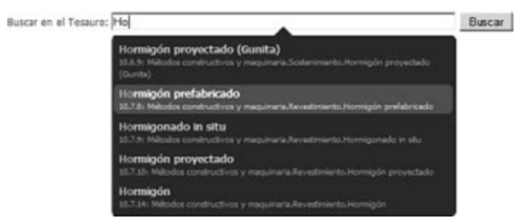

Figure 3. Example of searching information by "Auto filling".

Figure 4. Example of the results obtained from the search.

are dynamic, this means that can be modified when necessary so they are stored in CSV format which can be actualized automatically and independently to the PHP code.

On the other hand, when searching information, the tool can search by title and/or description, by keywords from the thesaurus or by whatever field of metadata implemented in the tool.

The result is a list of all the IO coinciding with the search specifications.

4 FINDINGS

4.1 *Expected results*

For GAC, the following results are expected during the project.

- Improvement of knowledge transfer in the field of subterraneous.
  By creating flexible and attractive methods for user contributions, GAC will provide the infrastructure to create a sustainable, dynamic knowledge network. Dissemination and community building work will ensure the growth of an active user community connecting professional and academic experts. The portal will exist in a first prototypical form early in the project and will gradually evolve.
- Integration of content from various sources.
  Integration of GAC into other or upcoming projects.
  GAC will start with the contents of the "Multidimensional city" but it will combine a lot of content from very different sources, making it available through a single access point which does not exist at present. The amount of contents available will increase over the duration of the project. Other or upcoming projects in the field of subterraneous works can use GAC as base for their activities or partner.
- Increase in usage of content.
  The GAC approach will provide unique search and knowledge discovery facilities in the area of subterraneous work. Integrating GAC services into existing content networks will hugely increase content acquisition and usage across repositories.
- Creation of methods for enriching content repositories.
  GAC will define different types of metadata for tagging contents: traditional content metadata, context metadata and usage related metadata. Close integration of universities as well as professionals ensures that demands from the user side are recognized and fitting solutions will be created.

The GAC project started in September 2007. The infrastructure is already created and the knowledge and information is being analysed due to the fact that the "Multidimensional city" project started two years ago and many results and finding were obtained during this period.

Currently, our research group is creating protocols and standards for the other partners to use the GAC properly and to metatag their knowledge. To do so, our group is analysing what is being done for the moment (deliverables, presentations, simulations, etc.)

The system developed by GAC is being used as a pilot in "The multidimensional city" and then it will be spanned to other projects.

The idea of this system is:

- To avoid creating existing knowledge
- To define storage and search criteria to codify, collect, store and disseminate not only explicit knowledge but also tacit
- To allow continuous updates of the database by incorporating other systems related to the research area
- To provide to academics, researchers and industries with knowledge specific to a research field.
- To transfer to all the project partners the research finding of the other partners. This is very important in big projects but it can be extrapolated to different projects on the same field.

5 CONCLUSIONS

Currently, the majority of the research knowledge is shared:

- In face-to-face interactions (project presentations, meetings, etc.) or
- In conferences or journals

Then

- the knowledge is limited to specific people.
- when the journal is published it is about one year from its creation so it is outdated.

– the knowledge is dispersed in different supports (paper based, on line, etc.)
– the knowledge is not codified

What is intended with this system is that tacit and explicit knowledge can be converted into codified knowledge to give access to the whole community of practice or interest.

It is then necessary to change the individuals and organisational culture. End users should have the willingness to share knowledge and time for that.

ACKNOWLEDGEMENT

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Mixed approach for SMARTlearning of buildingSMART

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ABSTRACT: BIM (Building Information Modeling) and buildingSMART is a new upcoming subject in the AECO, (Architect, Engineering, Construction, Owner) industry. This will also result in demands to the education system. BIM and buildingSMART is not only about software. It is therefore important that the students internalize the attitude that BIM and buildingSMART is concept for object oriented exchange of information who offers new ways of solving problems and collaboration. To achieve this, we need a mixed approach, focusing on both process and use of software programs. We have developed a P-P index (Program – Process index) for classification and management of education. Use of team work in problem and project oriented methods makes the students to a self learning unit. Lack of BIM/buildingSMART education is expected to be one of the major bottlenecks in the implementation of new ways of integrated collaboration and increased use of BIM and IFC compliant software.

1 INTRODUCTION

1.1 *Scope and framework for this paper*

The background for this paper is different experiences attempting to teach engineering students about BIM (Building Information Modeling) and buildingSMART. (This paper notates this as BIM/buildingSMART). The origin of the "mixed approach" was experiences in the "Design of Buildings and Infrastructure" course with 160 students working in teams of five. The students were in their second of the five year master study in Structural Engineering at Faculty of Engineering Science and Technology at Norwegian University of Science and Technology (NTNU). This approach has later been used in other introduction courses at NTNU, e.g.

Experts in Team (Syvertsen 2008) and at the Master in Technology study in and Architecture at, Norwegian University of Life Sciences (UMB). The mixed approach has also been useful when mentoring students with their master thesis.

Introducing use of new ICT tools, e.g. BIM/IFC-compliant software, is regarded by professors as a high risk case (Haavaldsen 2007). Software problems easily leads to dissatisfaction problems, stress among the students related to reduced marks on delivered reports due to these problems. Focusing on process was tried out as a counterweight to the software program focus.

1.2 *The supply for buildingSMART in the education*

An internet search for education in use of buildingSMART, BIM, Building Information Model, IFC and similar concepts give limited response. Even if we supplement the list of education to the buildingSMART organization (Scuderi 2008) with education at profiled universities, such as Georgia Tech, University of New South Wales in Australia and CIFE at Stanford University, the result is improved, but the overall result is relatively limited.

Some courses offered under BIM/buildingSMART profile are just a copy of old course and curriculum in CAD design, but using BIM/buildingSMART compliant software. This will make it difficult to discuss and evaluate BIM/buildingSMART questions. This will not be better if BIM/buildingSMART is becoming the new buzzword (Eastman et. al. 2008). Use of our P-P index, (Program-Process index) in figure 5 can be a tool to expose the real content of the course.

On the other hand, the supply is increasing. I addition to universities, education on university level can be offered by research organizations. One example is the SINTEF Group in Norway, who offers introduction courses in buildingSMART subjects (IFC buildingSMART) and IFC/IDM (Information Delivery manual) and IFD (International Framework for Dictionaries). Some software developers/vendor are also offering courses or BIM introduction information.

But the possibilities can be better than a shallow internet search identifies (be aware of the iceberg effect). On the MSc. in Technology in Structural Engineering at NTNU in Norway it is now possible to carry out total one of the five year with specialization in buildingSMART subjects. Due to administrative rules this can yet not be displayed as a specialization. The BIM/buildingSMART courses are offered as optional project course, with the original wide defined names as "Experts in Team" – but with new content. Standard lecture courses and compulsory education in this field will come, even if it takes some time to get it trough the "system".

An interesting issue in this sector is to look after if it there has been a change in focus and curriculum, or if it only a change of software. Especially the assessments criteria must be adapted to information content with multiple presentations and use of electronic hand in of BIM files. Of course can the project also include posters and live presentations, but the information content in the BIM must be weighted and assessed professional. This requires that the external examiner can use BIM/IFC based software, which can be a problem in the universities. Support and collaboration form industry is thus needed.

1.3 *The need for buildingSMART in the education*

Large builders like the national administrative building bodies in the USA (GSA; www.gsa.gov/bim), Norway (Statsbygg; www.statsbygg.no), Finland (Senate Properties; http://www.senaatti.fi) and Denmark (DDB; http://www.detdigitalebyggeri.dk) are starting to demand BIM files as their project documentation instead (or in addition) to drawings and text. This development will only increase and set focus on both software development and BIM related skills.

According to Eastman (et. al. 2008) will the lack of appropriately trained professional staff, rather than the technology itself, become the current bottleneck to widespread implementation of BIM/buildingSMART. Senior adviser Mohn (2008) in The Norwegian Defence Estates Agency says that buildingSMART will change role-patterns between the unequal profession groups in the industry. A demand for new competence will come in addition or instead of the present ones.

NBIMS (2006) in USA has also set education on their schedule and asking how we develop the BIM modelers of the future that will be in such demand. No clear answer was given.

1.4 *Does BIM/buildingSMART require a new profession?*

Several persons in the AECO industry points out that BIM/buildingSMART require a new profession. Dominic Gallello (2008) set focus on the BIM Manager as the hub in utilizing BIM/buildingSMART. The BIM Manager must have both IT technical and AECO knowledge. This role is different from CAD manger. In the BIM Handbook proposes (Eastman et. al. 2008) two new roles: 1) Systems Integrator – this function will be responsible for setting up exchange methods for BIM data with consultants inside and outside the firm. 2) Model Manager – while the protocols for version control and managing releases are well developed and understood within the drawing document based world (whether paper or virtual), options are different and more open ended with BIM. The Model Manager solves these issues.

The suggested roles must be seen as just some of several possible and dedicated new roles in future AECO industry. It is therefore important that the students are aware of the organizational impact, and not think that there is only one role connected only to use of software. Different levels in the organization demands different skills. It is therefore important that reflections about organizational changes must be included in the BIM/buildingSMART curriculum.

2 THE BUILDINGSMART APPROACH

For technical information about BIM and buildingSMART we recommend the www.buildingsmart.com/web-site or the books and sites presenter later in this paper.

2.1 *What is BIM/buildingSMART*

In addition to extensive use of acronyms, BIM/buildingSMART itself is not an exact concept. A lot of different understandings and definitions are in use.

In this paper we define BIM/buildingSMART as a concept (an idea, or an attitude) for object oriented exchange of information that can be supported by use of software. In this perspective is IFC a concept for un-proprietary transparent file format for exchange of BIM from software to software. Use of IFC will always include "BIM".

Eastman et. al., (2008) points out that BIM is not a thing or a type of software, but a human activity that ultimately involves broad process changes in construction. Another factor to be aware of is that BIM is becoming a huge buzzword in AEC. It shows up in every magazine; there are multiple conferences a year about it; software developers headline their products as BIM tools.

2.2 *From CAD to BIM – find & replace*

When going form drawings on paper to CAD on screen, one could maintain the traditional and well performed working patterns. It was easy to follow the

Figure 1. From CAD to BIM by Find & Replace?

progress of quality; from sketch on cheap tracing paper transparent paper, to use of expensive plastic drawing sheets for the final versions. This established the layer structure, but had it limitations due to transparency of paper/plastic – and use of color. With BIM you can not see the difference on the drawings or on the screen if it is "a nice drawing". The information is inside the model and you have to do something with the model to view the content.

The technology transfer from CAD to BIM/ buildingSMART can not be realized only by buying new software tools. The organizational challenges and benefits must be taken into account.

2.3 *Need for new ways of information diffusion*

The AECO industry has many professional domains, and everybody has their own terminology, technology, style and structure of information. Also within the same professional area, it seems to be considerable communication fault and loss of project information. Estimates from The Norwegian Homebuilder Association (Sjøgren 2007) indicate that 25–30% of the construction costs is related to the splitting up of processes and bad communication. The same information is average input at least 7 times in different software systems. The same results/analyses are also created on again in several applications. The buildingSMART alliance has as its goal to improve this history by making a shift from today's document focused situation illustrated in figure 2. below:

To tomorrows use of a common product model illustrated in figure 3. below:

The access to information will be managed so, that each role; architect, consultative engineer, public authority, contractor, subcontractor trade, craftsman, manufacturer and building owner get access to right information when needed.

2.4 *Information exchange in the industry*

A study conducted by Aragon (2006) asking for the five most used file-formats showed that MS Word, Adobe PDF, and MS Excel was set up in 70 – 80% on the top five lists. The graphical file-format JPG score was 50%, and 3-D and DWF was listed in fewer

Figure 2. Exchange of information by use of documents. (Sjøgren 2007)

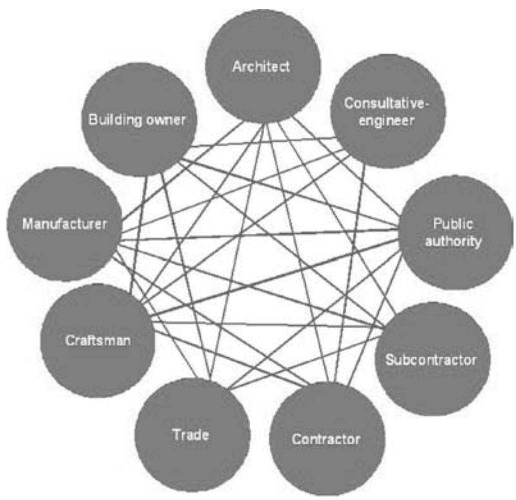

Figure 3. Exchange of information by use of common product model.
(Sjøgren, 2007)

than in 10% of the five top lists. It was relative small differences between architects, engineers and owner/operator. The problem with information exchange was: delays in receiving input, challenges in communicating across time zones, people using incompatible software applications, and difficulty interpreting of feedback. This study also demonstrates the relative limited use of drawings compared with drawings (should the architecture study include courses in word processing?). What if information exchange in drawings could contain text and figures – in what we defines as BIM – and could be exchanged independent of software vendor by use of IFC – in what we defines as buildingSMART!

2.5 *ISO standards in buildingSMART*

The development of buildingSMART compliant software programs is based on the international ISO standards.

IFC – (Industry Foundation Classes) – is an exchange format that defines how to share the information. IFC is build on ISO/PAS 16739, and is an object oriented data model for management of information. IFC is a model for un-proprietary (vendor independent) file format.

IFD – (International Framework for Dictionaries) – is a reference library to define what information that is being shared. IFD is built on ISO 12006-3:2007. IFD enables a smart way from generic to specific building parts.

IDM – (Information Delivery Manual) – Defines information requirements about which information to share when and with who. IDM is under development as ISO/CD PAS 29481-1 by standardization group ISO TC59/SC 13.

3 MIXED APPROACH

3.1 *Classification of BIM/buildingSMART education*

The mixed approach for learningSMART of buildingSMART is a pedagogical realization of the dialectic content of BIM/buildingSMART with both focus on software and working processes.

We have developed the P-P index (Program – Process index), see figure 5 below, for classification, measurement and management of the mix of software program use and focus on process.

Education can by this method be classified by use of the P-P index. E.g. an education who is classified to 6–3 (program = 6, process = 3) indicating widely use of different software tools, but with relative little focus on how one is working and collaborating.

An important issue is that the weighting of the two parts can be dynamically, letting the best part dominate when grading. This made it possible to manage technical problems, or limitations of guidance in favor of the students.

3.2 *Use of mixed approach in "Design of Buildings and Infrastructure"*

The "Design of Buildings and Infrastructure" course at NTNU is a compulsory course with 160 students, taken in second of the five year master study. The students were collaborating in teams of five students. The project task was compounded of a program

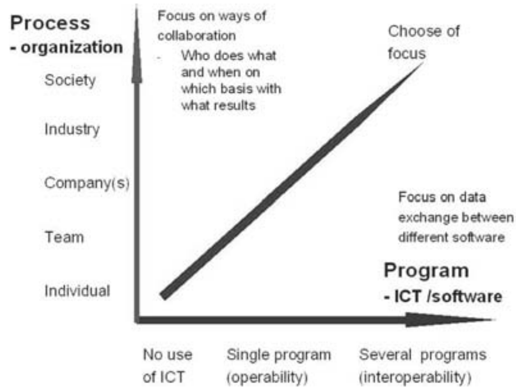

Figure 4. Choose of focus in BIM/buildingSMART education.

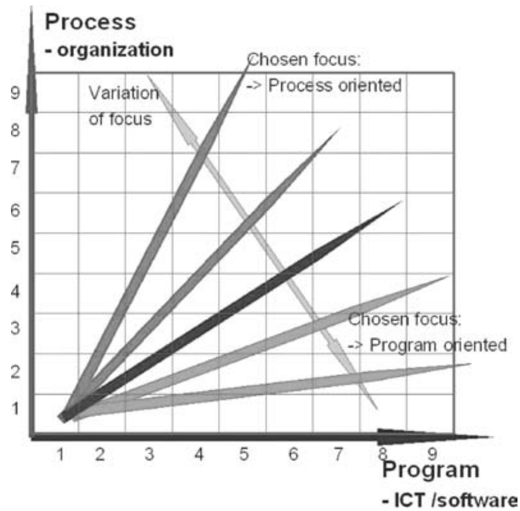

Figure 5. The P-P index of BIM/buildingSMART (P – P = Program – Process).

part and a process part. In the "Program part" they where using IFC-compliant BIM software (The Data Design Systems programs; ArchitecturePartner, ConstructionPartner and IFC-viewer) to design models of self defined buildings. They where given a 3 hour "crash course" in the software, and a learning manual. The rest was done by learning of each other and use of an electronic "help-desk" for software questions and tips. The assessment of the model was done on both degree of solving architecture/engineering problems and level of information content in the BIM/IFC model. The "Process part" was writing of a report where they should make their own reflections of use of BIM/IFC in projects. This part was also supported with input for theory notes/articles/viewpoint from the industry, software developers/-vendors and research.

Figure 6. Life long learning perspective.

To motivate for this perspective we illustrated it by figure 6 for putting the perspective outside the short project period.

Long term perspective is needed because of complex challenges (problems) with file-/information transfer between different software tools – and for adaptation of new ways of working and collaborating in the industry.

The "mixed approach" has been used in lecturing other BIM/buildingSMART courses at NTNU and at UMB. This perspective has also been useful when mentoring students in their work with the master thesis.

3.3 *Software challenges and possibilities*

– Technical problems
  When (unfortunately not if) they occurs, it is important that the students do comprehend that this do not get negative consequences for the assessment of their project work, e.g. make delays or can't perform parts of the project work in right time. Installation, license problem and access problems due to network/firewall are examples of experienced obstacles.
– Guidance in use of software
  There is a disproportion between the time one is skilled inn the software and how much time it is left on the project. Focus on a motivating "start up" – and do not demand difficult program use. – students do learn the (very) difficult function by them self and by others, when they self think it is need.

  Long lasting software courses can sometimes be negative. It takes much time on one specific program, who they think must be used. This can decrease the free use of programs and combinations.

  Give access to a lot of software – and let the students use it in their own way.

3.4 *Lessons learned*

BIM/buildingSMART projects are really fun!

As a paradox, the student "complained" that they spend too much time in this project related to other (boring) courses. Open-ended projects sometimes need a "moderator" for limiting "competition" and over use of time on marginal issues. The assessment criteria can be used for this purpose.

Students collaborating in team can become a self developing learning unit. This reduces time for software training and support.

Have a back-up plan for software and other ICT problems. Students will often (note: there can be some differences dependent how high the focus on good marks are) over focus on this in the course evaluating. A mixed project and use of assessment can reduce negative comprehensions among the students.

Do not forget to have fun! This is the fuel for the learning process. Appreciate the problem solving process – and listen to the students – and learn from it.

3.5 *"Mixes" between universities and industry*

The development of BIM/buildingSMART is mainly industry-driven. Universities (and other educational institutions) will have benefits from collaboration with industry in getting recourses for software and instructors. The industry can have the role as the "problem-owner" in master thesis and other projects. On the other side will the industry get more qualified employees. The rate of return will be very high and should indicate increased investment.

4 EDUCATIONAL TOOLS

4.1 *BIM-lab with IFC compliant software*

BIM/buildingSMART education is often based on use of several software programs, used in a very varying degree. Many software vendors offer free licenses for universities and students. Collaboration with the industry will normally give access to commercial software in dedicated courses and/or for students working with their master thesis.

To select IFC compliant software, use "Software" at the www.buildingsmart.com web-site on find "IFC compliant applications database" (direct link: http://129.187.85.204/fmi/iwp/cgi?-db=IFC-Applications&-loadframes)

4.2 *Textbooks and sources of information*

The supply of textbooks was earlier a problem, but today following textbooks and internet sources can be a good support:

Textbooks
– BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors. Eastman, C., Teichholz, P., Sacks R., Liston K., 2008 John Wiley & Sons, Inc. www. ISBN: 978-0-470-18528-5
– BIG BIM little bim. The practical approach to building information modeling Integrated Practice done the right way! Finith E. Jernigan, AIA. www.4sitesystems.com. ISBN-13: 978-0-9795699-0-6

– Green BIM successful sustainable design with building information modeling/Eddy Krygiel, Brad Nies. www.sybex.com/go/GreenBIM . ISBN 978-0-470—23960-5

Internet:

– BuildingSMART http://www.buildingsmart.com/
– National BIM Standard http://www.facilityinformationcouncil.org/bim/index.php
– ITCON http://www.itcon.org/
– AECbytes http://www.aecbytes.com/
– BIM Recourses @Georgia Tech http://bim.arch.gatech.edu/
– "google" after the concepts and acronyms, and do not forget discussions with other!

4.3 *BIM manual*

Use of BIM manuals can be a way to set focus on skillful use of software and information content. Several countries have now developed their BIM manual to their own codes.

USA: – General Services Administration (GSA) 3D-4D Building Information Modeling BIM Guide Series USA: – National BIM Standard (NBIMS): http://www.facilityinformationcouncil.org/bim/index.php

Germany: – IAI German Chapter:Anwenderhandbuch http://www.buildingsmart.de/2/2_02_01.htm

Denmark: – Det Digitale Byggeri http://www.ebst.dk/detdigitalebyggeri

Norway: – Statsbygg (Norwegian government as property manager) BIM manual: http://www.statsbygg.no/FilSystem/files/prosjekter/BIM/Sb_BIM-manual_v_1_00.pdf

Finland: – Senate Properties' BIM requirements 2007 – BIM Guidelines http://www.senaatti.fi/document.asp?siteID=2&docID=517

4.4 *The BIM staircase*

The "BIM staircase" in figure 7 can be used as a tool for measuring development in a BIM/buildingSMART course, or for comparing different courses. Interoperability is classified as; **T**echnical, **S**emantic or **O**rganizational.

4.5 *Assessment – learning – teaching*

As pointed out before, assessment is a powerful tool in management of education. Figure 8 shows the interaction between assessment – learning – teaching.

– Teaching emphasizes what lectures do
– Leaning emphasizes what the lectures do
– Assessment emphasizes what students can show what they know

Task	Inter-operability		
	T	S	O
6. Integration with other systems	X	X	X
5. Integrated analyses, use of rule-checker	X	X	X
4. Interoperability for all IFC compliant software	X	X	
3. BIM used, exchange between defined software programs	X	X	
2. Use of single BIM application	X		
1. Use of 3 D model with render	X		
0. Use of 3 D model (BM) No information in objects	X		

Figure 7. The "BIM staircase" for classifying and defining BIM/buildingSMART level.

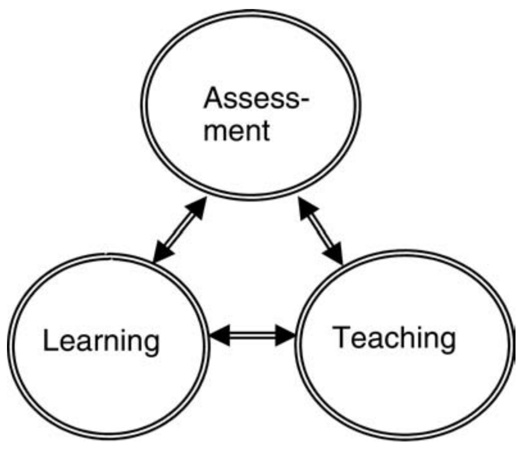

Figure 8. Assessment – Learning – teaching.

Figure 9 indicates use of assessment as a tool easier follow the red line to targeting the learning objectives.

4.6 *Pedagogic theory*

Constructivism is a beneficial theoretical foundation for project- and problem-based learning and in BIM/buildingSMART education. According to

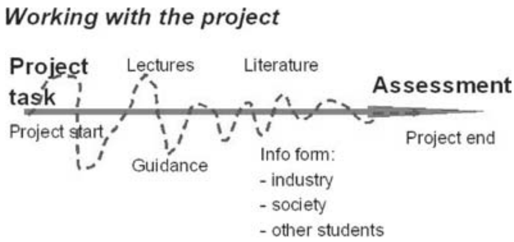

Figure 9. Using assessment for targeting the learning objectives.

Learning Theories Knowledgebase (2008) constructivism as a paradigm or worldview posits that learning is an active, constructive process. The learner is an information constructor. People actively construct or create their own subjective representations of objective reality. New information is linked to prior knowledge, thus mental representations are subjective. Originators and important contributors are Vygotsky, Piaget, Dewey, Vico, Rorty, and Bruner. Blooms (1956) taxonomy is useful tool for being conscious about the level of learning in the education.

4.7 *Different learning styles*

Christiansson (2004) says that we in fact right now is in the middle of an intense development phase where creative ideas on ICT tools and tools to design tools (meta tools), as well as new organization of the learning environment and enhanced pedagogical methods are tried out. Development of the BIM/buildingSMART is an interesting recipient for these results.

About levels of organization, Moum (2006) set up a framework founded on the suggestion of three hierarchical building project levels; the micro (individual)-, meso (group)- and macro (overall)-level. This hierarchy can be seen in relation to figure 7 about the BIM staircase.

A discussion in the Viewpoints on AECbytes.com between Renée Cheng and Paul Seletsky points out different approaches and attitudes. Cheng (2006) points out that many educators worry that design thinking will be jettisoned to make room for new content. Not only is there competition for students' time, but there are two competing philosophies: BIM is inherently answer-driven, design thinking is question-driven. The fear is that heavy emphasis on "how to" guarantees a loss of the critical "why."

Paul Seletsky (2006) is in a different opinion and says that when BIM is defined as a process – as it should be – it begets per formative information and simulative environmental conditions into design, placing an emphasis on "the underlying logic of design". It uses digital means to enable critical analysis of such data and, most importantly, engenders its exchange between architects and engineers via new collaborative methods.

These Viewpoint articles are just an example on discussions about BIM/buildingSMART in education. This indicates that there is no a right or wrong answer, but good or limited enlightenment about the interconnections in the educational conditions.

5 DISCUSSION

The empirical foundation for development of BIM/buildingSMART education must be extended before too strongly held views can be set or "Best practice" established. One must open up for a more experience driven development, in stead of constructing the best education "on paper". Students will contribute with useful input. According to the hermeneutic spiral (Shanks, 2008) learning has to mature to be really understood. And that learning can consist of learning, de-learning and re-learning. The education must therefore be adaptable. What is good today is not necessary the right way tomorrow. Better and more interoperatible software and an increased interest from the industry will change the framework for BIM/buildingSMART education.

For further development of BIM/buildingSMART education an establishment of an Edu-BIM-forum for sharing experiences can be a suitable way. This initiative should be supported by the industry with programs and people (instructors) and projects.

6 CONCLUSIONS

Education in BIM/buildingSMART should contain a mix of use of software programs and focus on process. The proposed P-P index (Program-Process index) is a 9×9 matrix (figure 5) that can be used for classifying the content in the education.

Assessment is a powerful tool for management of the education and enables interaction between assessment – learning – teaching. Conscious use of this is very important when balancing mixed approaches.

Project- and problem based learning with students collaborating in teams are suitable for working with versatile BIM/buildingSMART projects.

The future will demand professionals with BIM/buildingSMART skills. Support and recourses form the industry is needed for developing and implementing BIM/buildingSMART based education. This will give a win-win situation.

Go ahead and realize your dreams!
BIM/buildingSMART will boost the education in a new way – and you will practice "Learning by doing". (Dewey 1956).

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Implementation of an IFD library using semantic web technologies: A case study

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ABSTRACT: Information technology tools and methods have been in use in building industry for over three decades. Utilization of IT tools such as computer-aided design applications in the building design phase is pervasive. However, CAD drawings do not suffice the requirements of effective building models. IAI IFC models have been introduced as means of providing a higher level of data integrity and utilization potential in all phases of the building life cycle. In this context, International Framework for Dictionaries (IFD) can enrich design tools with specifications beyond geometric information (e.g. material, construction, schedules). These libraries can be equipped with ontologies and shared on the web. Having a semantically enriched, searchable library of building products can support designers to efficiently select those products that best match design constraints and criteria pertaining to specific projects. In this paper, we will present a case study of an IFD library for a specific building component (skylights) that has been implemented based on Semantic Web technologies and shared via Web Services.

1 INTRODUCTION

The building industry is embedded in a complex web of relationships that affect building design. The building design process relies on large databases that are often managed by human knowledge and interactions. However, information from such databases can only be utilized in specific projects if contextual parameters such as country-specific standards and policies are considered. Effective mapping of relevant contextual attributes onto available building industry information has a formidable potential to improve the design process: Design options and alternatives could be more readily assessed and compared by providing semantically enriched building models to evaluation applications (e.g. performance simulation programs).

During the design phase, architects and engineers must make some critical decisions about building components and materials to be used. Provision of computational support for this decision making process would benefit the AEC stakeholders in view of cost reduction, energy efficiency, and occupants' comfort and productivity. To illustrate such a multidimensional decision making problem, we focus on the example of a specific decision making scenario, namely the selection of specific building products during the design phase. In the present contribution, we take the example of skylights. According to this scenario, the selection of a proper skylight product is dependent on multiple factors such as client requirements, space functions, visual and thermal requirements, structural constraints, design concepts, and budget. Any decision toward selecting a specific skylight product must not only comply with the applicable requirements and criteria, but also evaluated in view of resulting performance (energy, daylight, etc.). Note that the specific application in this case (skylights) and the associated computational tools (energy calculator) serve here as illustrative instances. As such, similar processes can be implemented for other – and more realistic – application scenarios in building design and construction domain.

Today, there are many different media (catalogues, CDs, internet), which entail information on building products and their relevant technical information (Mahdavi et al. 2004). However, most of this information is neither in a standard format nor machine processable (in a semantic way). The use of IFC as the common template for information sharing (Halfawy et al. 2002) and the application of semantic Web Services as the communication method can address this problem. Previous work has already proposed IFC-based online construction product libraries (Owolabi et al. 2003). IFD is the current trend in

IFC-based product libraries, where concepts and terms are semantically described and given a unique identification number. This allows all information in IFC format to be tagged with Globally Unique IDs (GUID) (Bell et al. 2006). As a result, the building component data will no longer just reside in a generic repository of components embedded in a specific design tool, but they can be dynamically extracted from IFD libraries via user inquiries. The completed model (generic component model as well as specific and concrete product information) can then be immediately accessed by IFC compatible Web Services in real time and communicated dynamically to other services for simulation and evaluation purposes. By using IFD libraries (Bjørkhaug et al. 2005) and IFC-compatible services the power of the building information model can be substantially increased.

In this paper, the implementation of an IFD library using Semantic Web technologies is explored and, as a proof of concept, the SkyDreamer prototype is presented. Thereby, information from a semantically based IFD library is obtained to enrich a generic building model in IFCXML format. Subsequently, this enriched model is communicated to web-services for simulation, analysis, and evaluation purposes.

1.1 *BuildingSMART, BIM and IFD*

The International Alliance for Interoperability (IAI) (IAI 2008) defines the buildingSMART as "integrated project working and value-based life cycle management using Building Information Modeling and IFCs" (IFCWiki 2008). The focus of buildingSMART is to guarantee lowest overall cost, optimum sustainability, energy conservation and environmental stewardship to protect the earth's ecosystem (BSA 2008).

Building Information Models (BIMs) that conform to IFC model, build the core of this vision. BIM conveys all required information for the whole lifecycle of the building. The buildingSMART vision will be realized when the following three pillars are in place:

1. IFC standard as the exchange format for sharing the information
2. IFD as the reference library to define what information are being shared
3. Information Delivery Manual/Model View Definition (IDM/MVD) specification to define which information is being shared and when

To clarify the issue these three pillars can be compared with World Wide Web standards:

1. HTML defines the exchange format of web pages
2. Website conventions that defines the logical components of websites (menus, contact page, etc) and their relationships (Note that the conventions are just a meta-model and instances of this schema will be defined by HTML).
3. HTTP protocol defines the communication protocol between client's browser and web server

As we browse to a website, all these three pillars are working together to make it possible.

The IFD library, similar to website's schema is a mechanism that allows distinguishing concepts (AEC entities like wall, door, window, etc) from specific linguistic instances (English, German, etc), names and real world instances of those concepts. So for example, all translations of the term "window" (Fenster, Finestra, etc) will refer to the underlying entity. These concepts are equipped with a Global Unique Identifier (GUID) that is used to refer to this concept in all instances.

1.2 *Semantic IFD libraries*

The Semantic Web (Berners-Lee et al. 2001) is a web of data that enables machines to "comprehend" the data. Until recently the information available on World Wide Web was solely human understandable. The Semantic Web aims to change this information into knowledge resources with a well defined meaning that will enable the computers to intelligently process this information. The resources in the semantic web are identified using unique names called Uniform Resource Identifier (URI) (Berners-Lee et al. 1998). A resource can be anything such as a person, a document, a product technical drawing, a testing tool specification, a business process or a service which is further described at the specified address pointed by the URI (Anjomshoaa et al. 2006). URIs are the basic block of the semantic web and can represent information in a graph-like structure. The resources should conform to a "specification of a conceptualization", or ontology. In simple terms, it is a set of shared vocabulary, arrangement of related taxonomy, and the definition of axioms to specify the relationships between them.

The next generation of World Wide Web will be greatly affected by this new, evolving technology that will have significant economical impacts. It is important to note that despite this classical definition of semantic web, which is coupled with Internet and World Wide Web, the technology has been widely accepted and used to capture and document context information in many fields. For example, in this paper, the semantic web technology has been used to define domain information about AEC products such as skylights. In addition, it makes the building model readily available for integration in processes through specific web services to outside world. Furthermore, the semantic web provides a uniform view of information, which is independent of its encoded language and its medium type (Internet, CD, catalogue, etc).

By making use of suitable ontological commitments the ontologies can successfully be integrated in AEC concerned domain such as IFD libraries.

A pre-requirement to the existence of such a library is of course a coherent and consistent ontology which can be understood and used by all processes and applications. The ontology that has been used for the use case of this paper is created based on Industry Foundation Classes (IFC). IFD standard on the other hand also uses IFC model to share the building object information in a comprehensive and processable way for other IFC compliant applications. In other words, the IFD library can be seen as a collection of ontologies that can be used to describe things in IFC. This idea is fully compatible with semantic web concepts (Tjoa et al. 2005), where ontologies represent the shared knowledge in a specific domain and in this sense the IFD plays the role of ontology schema. Moreover the GUID of IFD concepts can be also compared with Semantic Web's URI notion that defines the resources in ontologies.

As a result, the IFD libraries, which are fully compliant with Semantic Web concepts, can also benefit from well-established architectures and tools of semantic web and extend the footprint of libraries in AEC applications.

It is important to note that IFD does not include any instances of the elements, rather it defines the abstract concepts that can be instantiated and materialized using IFC standard.

In the rest of this paper, the term *IFD library* is used to refer to a Semantic IFD repository of elements that is based on an IFD library and includes the real world products. Thus, the IFD library concept in this paper should not be confused with the basic definition of IFD library that cannot include the instances.

2 SKYDREAMER PROTOTYPE

SkyDreamer has the following five basic parts (see Figure 1):

- *Semantic repository* stores the skylight product information in a semantic way. The Skylight ontology extends the core IFC2X3. The semantic repository can then be queried via Joseki Servlet (Joseki Servlet 2008).
- *Building's navigator* facilitates the selection of desired space from the building's hierarchy of zones and spaces.
- *Web extraction component* parses the product information pages from the available sources on the web and stores them according to the skylight ontology. In our case study, we have made a plug-in for "Certified Product Directory" (CPD 2008) that lists the certified products categorized by type and producer.
- *Calculator* receives the building model in IFCXML format and calculates the energy use implications of the selected skylight component (extracted from Semantic-based IFD library) for lighting, heating, and cooling.
- *User interface* that interacts between the end user and other system components such as calculator and semantic repository.

2.1 *Semantic repository*

To establish a Semantic IFD Repository, two basic parts are needed, namely: An ontology schema that describes the required elements and the instances.

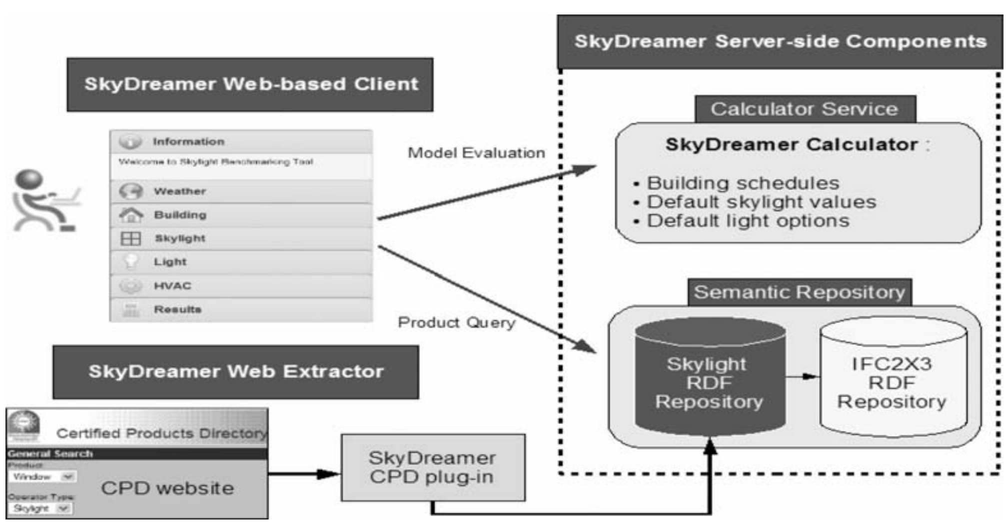

Figure 1. SkyDreamer components.

In this section, the process of creating the ontology schema and populating the library elements (instances) will be explored.

In Semantic Web projects, it is common to create a shared understanding of concepts or high level ontology at the very early stages. In AEC field this common understanding already exists and IFC standard provides the basis material to build an ontology. For the purpose of the SkyDreamer use case, we used the EXPRESS (ISO 10303-11) release of IFC 2×3 and transformed it to OWL by a translator called e2ont (e2ont 2008). The resulting OWL file that contains some errors and logical inconsistencies needed to be refined and corrected to be usable in the proposed prototype.

The other challenge of ontology creation was that the IFC standard does not explicitly define all building elements. Basically, the IFC model is a generic object oriented model that can be extended to define new elements. For example, we need to extend an ifcWindow to create a skylight with required collection of properties. A disadvantage of IFC's generic model is the fact that the IFC-based elements are not semantically well-organized and the format is more appropriate for object oriented computer processes. As a result the human user who needs to query the model needs to build complex queries to extract the required information.

Figure 2 demonstrates how properties such as Solar Heat Gain Coefficient (SHGC) are associated with a skylight component. Accordingly, to query all the skylights that have a specific SHGC value, the user should trace the tree from skylight (right hand side) up to the root and then the property sets (on the left hand side) and finally the specific property value pairs. To simplify the process, the Semantic Web's rules have been used to make a shortcut and attach the properties directly to skylight component. In the use case discussed above, the "hasShgc" predicate will be added to skylight components by applying the appropriate semantic rules.

Finally, the instances should be added to the semantic repository. For this purpose, a web extractor has been used that parses the resources on a specific website and adds them to the repository according to the ontology defined in step one. The web extractor is a simple Java application that runs periodically and synchronizes the repository contents with the website's information. The defined ontology (plus instances) has been shared with other SkyDreamer components as a web service. This feature is provided by Joseki Servlet which provides a semantic web query interface and a web service end point to query the semantic repository.

2.2 *Calculator*

The calculation component is also implemented as a web service and calculates the required energy for heating, cooling and lighting. The web service inputs are:

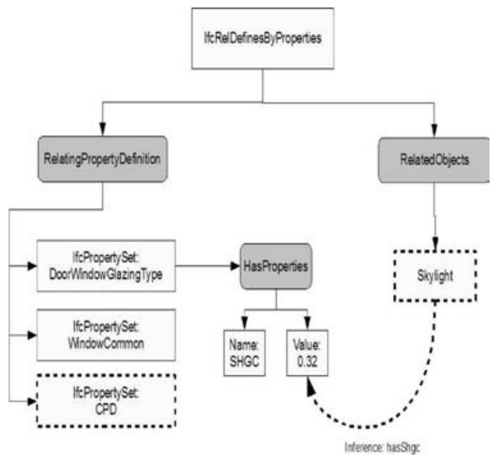

Figure 2. The IFC model and semantic inference.

- the building model in IFCXML format
- The weather file of the building location
- Building properties such as building type (residential, office, etc)
- HVAC options
- Generic skylight options such as glazing type and glazing layers, etc.

The calculator first runs the simulation process for a producer-neutral configuration and later on the user will be able to look for real products and repeat the simulation for real components from semantic repository.

3 RESULTS

In this section a typical use case of SkyDreamer is illustrated and the required inputs and user interactions are explained in detail. The presented use case has three basic parts, namely:

- Building configuration
- Simulation process
- Selection of Skylight component

3.1 *Building configuration*

In order to calculate the energy efficiency of a building a basic configuration is required (building description, including function, geometry, elements, materials). In the present scenario, user first provides the building model, which is used to extract room and skylight information. The building model environment is uploaded in IFCXML format. Alternatively, user may choose a default building model incorporated in the system. Subsequently, the "skylight to floor area

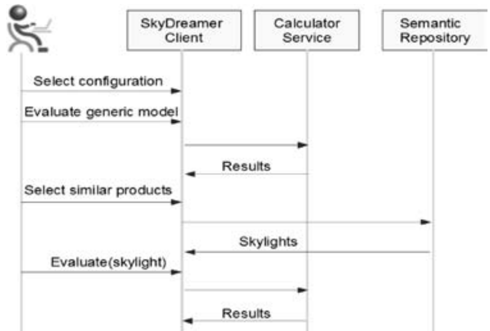

Figure 3. SkyDreamer sequence diagram.

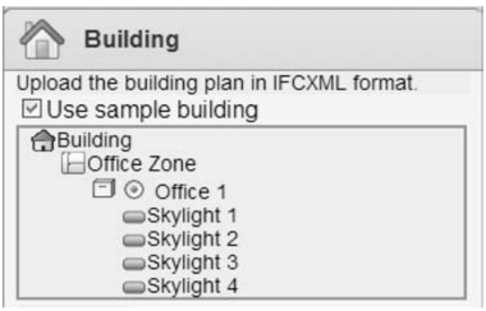

Figure 4. Building configuration.

ratio" (SFR) is derived for energy calculation in the following steps.

The currently implemented SkyDreamer's energy calculator is a simple one (single-storey building, rectangular floor plan) and serves for demonstration of system's capabilities. For more complex buildings a more sophisticated simulation program would be required.

To simplify the user interaction with the system, SkyDreamer is equipped with a building navigator. The user can select any desired space from the building's hierarchy of zones and spaces (see Figure 4). Given information on building and room functions, SkyDreamer can set the default schedules regarding occupancy, lighting, heating, and cooling.

The SkyDreamer calculator assesses the building's energy requirements (for heating and cooling) using a Java-based code developed by the authors that is based on the SkyCalc calculation procedure (SkyCalc 2008). Weather information can be either selected from preprocessed weather files for selected locations or generated and imported using eQuest 3.61 (eQuest 2008) (see Figure 5).

Next, the user needs to provide the physical characteristics of the skylights and light wells by choosing a generic product from the list. Based on this selection, the initial skylight's thermal and visual properties are assigned to the use case. These values can later be

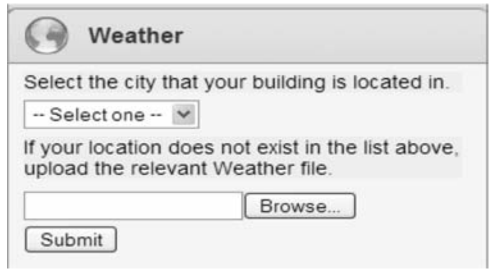

Figure 5. Selection of weather file.

Figure 6. Generic skylight configuration.

interactively modified by the user. The system identifies a real product with the corresponding user-desired property, and re-computes the performance indicators. Figure 6 shows the required properties that should be set for a generic skylight component.

In addition to the building model information mentioned above, SkyDreamer needs to know the properties of building's lighting and HVAC systems. For lighting calculation, the SkyDreamer calculator assumes a default lighting power density based on building characteristics and building type. Setting the Lighting Control option to "No Daylight" means the user wants to evaluate only the skylights' energy-related implications without daylighting controls.

3.2 *Simulation process*

After providing the building configuration, Sky Dreamer calculates energy demand for heating and cooling. The simulation result is also presented in graphic form that is suitable for benchmarking. After running the simulation for the first time, the user will be able to change the building configuration and run the simulation again (see Figure 7). As a result, this online simulation tool helps the designers to easily evaluate the effect of their design decisions.

3.3 *Selection of skylight component*

After running the simulation with generic skylight components, it is finally possible to select actual

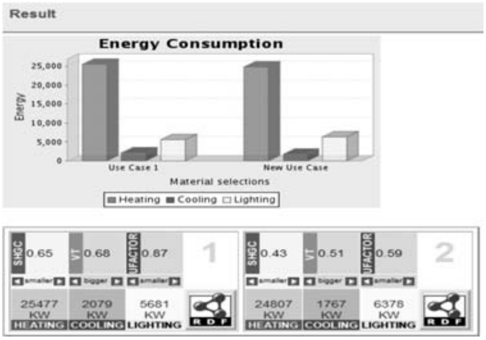

Figure 7. Simulation results.

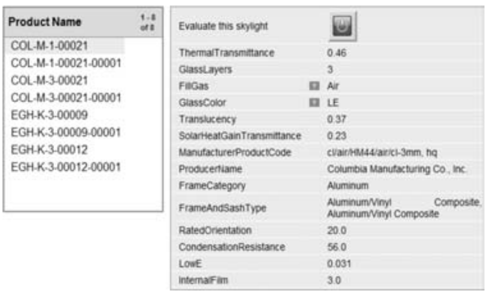

Figure 8. Skylight product query results.

skylight products from the semantic repository and re-run the simulation. The selection criteria are the SHGC, VT and U-value of the skylights. User can select his/her choice by altering the selection condition (larger, smaller) for each of these three parameter and the system will translate user's query into ontology query language SPARQL (SPARQL 2008) that runs against the semantic repository. As soon as the result is displayed, user can navigate through the results set and select the appropriate skylight component and repeat the simulation process. Figure 8 shows a sample query result that is rendered as HTML (the original query results are RDF).

4 CONCLUSIONS AND FUTURE WORK

The Semantic repository used in the SkyDreamer prototype as IFD library can be extended to cover other building components and to communicate with other web services. This implementation has demonstrated that elaborate semantic technologies can be used to bridge the gap between manufacturers' data, building information models, and web services. In future, we will extend the Semantic Repository to cover a more representative set of building components. Likewise, we intend to explore in more detail how powerful analysis and evaluation tools can be offered as web services in order to semantically enrich building models.

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Representation of caves in a shield tunnel product model

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ABSTRACT: A shield tunnel product model, IFC-ShieldTunnel, has been developed by expanding IFC of IAI based on the previously developed conceptual shield tunnel product model in this research. To represent excavated caves in ground soil layers in the product model, two methods, i.e., boundary surface method and cave object method, were proposed and compared. The cave object method was found to be more flexible and easier to use in the test implementation.

1 INTRODUCTION

Much effort has been seen in development of product models for building design and construction in order to enable the interoperability among heterogeneous application systems and software packages such as CAD, analysis, conformance checking, cost estimation, construction scheduling, for about a quarter of a century (Eastman 1999). Recently, Industry Foundation Classes (IFC) of International Alliance for Interoperability (IAI) seems to be becoming a world standard for building product models. Although about half of the shield tunnel works in the world exist in Japan, most of the detailed design and construction data have been owned and stored by the engineers who worked at the construction sites. Surprisingly, such precious and important data are not necessarily stored in construction companies and, thus, may be lost or may not be available when necessary in the future, which should be prevented by preserving the data in a systematic way. Thus, a product model for shield tunnels has been in the process of development in our research group to represent and preserve all necessary data in design, construction, and maintenance (Yabuki et al. 2007).

A conceptual shield tunnel product model was developed for representing objects such as members, components, facilities, geology, etc., processes of construction, organizations, various data and knowledge. Then, the conceptual model was compared with IFC to find duplicated or similar classes for deletion and new classes for inclusion.

During the product model development process, two problems were identified. One is how underground soil layers should be represented. The other is how caves of tunnels in soil layers should be represented geometrically. The first problem was solved relatively easily by adopting the "upper boundary surface" method. In this paper, the second problem, which is more difficult than the first one, is the issue, and two methods were proposed and compared in this research.

2 SHIELD TUNNELS

Shield tunnels are usually constructed for highways, subways, sewages, causeways, etc., where the open-cut method cannot be employed since there are buildings, houses, other structures, or river that cannot be removed above the route, mainly in urban areas. First, a shaft tunnel is excavated and parts of a tunnel boring machine (TBM) are descended from the top to the bottom and are assembled. A TBM consists of a shield and trailing support mechanisms. The front end of the shield is a cutting wheel, followed by a chamber. Behind the chamber there is a set of hydraulic jacks, which pushes the shield forward. A tunneling ring which consists of several precast concrete or steel

Figure 1. A photograph of a shield tunnel under construction in Tokyo.

segments is installed between the shield and the surrounding soil. The set of tunneling rings is called primary lining. If necessary, secondary lining, which is made of concrete, may be built. A photograph of a shield tunnel under construction in Tokyo is shown in Figure 1.

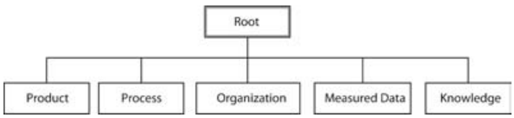


Figure 2. Five main classes of the conceptual product model.

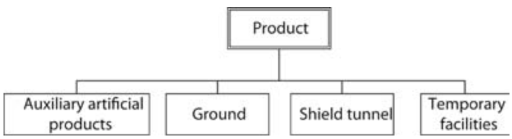


Figure 3. Four sub-classes of the Product class.

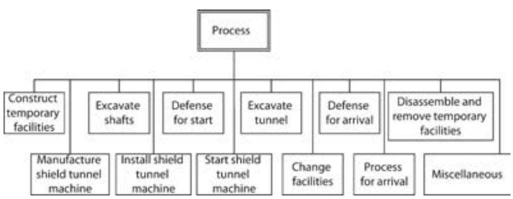


Figure 4. Sub-classes of the Process class.

3 SHIELD TUNNEL PRODUCT MODEL

3.1 *Conceptual shield tunnel product model*

Necessary data to be defined in product models would be summarized as 5W1H, i.e., when, who, where, what, why, and how. Thus, in the development process of a conceptual shield tunnel product model, Product for representing What and Where, Process for When and How, Organization for Who, Measured Data and Knowledge for Why, were put under Root of all classes. Figure 2 shows five main classes directly connected to the root class. Objects such as members, components, facilities, ground layers, etc., processes related to shield tunnel construction works, concrete organizations and stakeholders, various data and knowledge were listed up by investigating various documents of shield tunnels and by interviewing shield tunnel experts. In this way, a conceptual, hierarchical product model was developed for representing shield tunnels.

Figure 3 shows direct sub-classes of the Product class. The "shield tunnel" class has further more detailed and aggregated classes including void, primary lining, secondary lining, attached facilities, etc. The "primary lining" class has sub-classes such as segments, sealing material, bolts, and injected material.

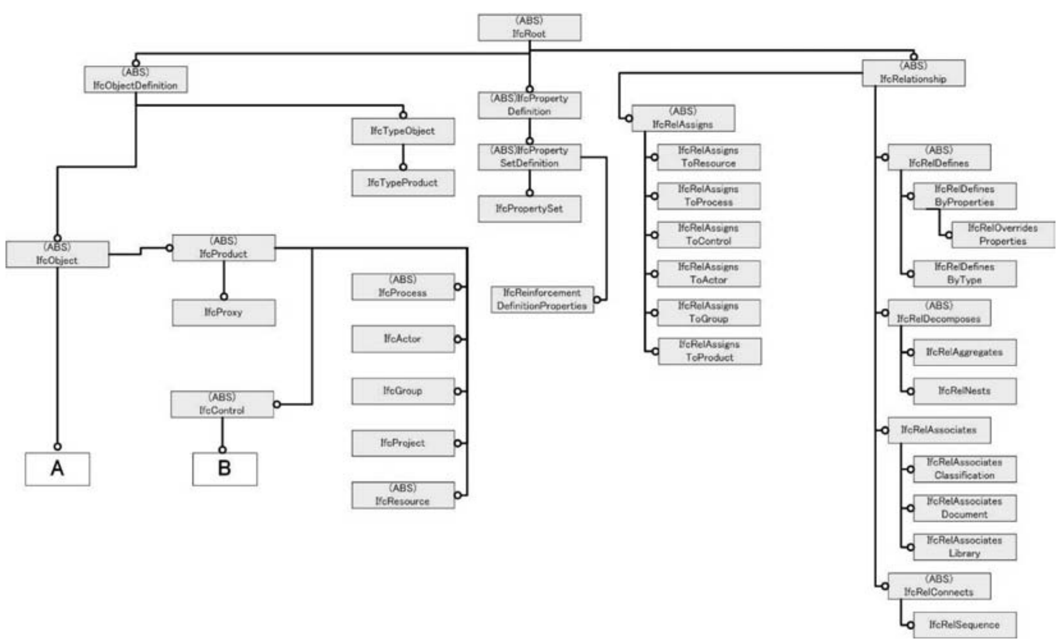


Figure 5. A part of IFC-ShieldTunnel (1).

Segments are classified as more in detail based n the material and shape. The "ground" class has sub-classes, underground layer and ground water. Figure 4 shows direct sub-classes of the Process class. These sub-classes have more sub-classes under them. Organization, Measured Data, and Knowledge classes have their own sub-classses.

3.2 *Implementation of IFC-ShieldTunnel*

The conceptual shield tunnel product model was implemented into IFC by adding necessary classes that had not been defined in IFC yet, such as shield tunnel specific members, temporary facilities, underground layers, etc. The product model was named IFC-ShieldTunnel because the development method is similar to IFC-Bridge (Yabuki et al. 2006). Figures 5–7 show some parts of IFC-ShieldTunnel product model. A part of the IFC-ShieldTunnel schema written in EXPRESS is shown in Figure 8, and an instance file of a part of an existing shield tunnel is shown in Figure 9–11.

As written in the first section, the first problem of representation of underground soil layers was solved by adopting the "upper boundary surface" method. In this method, each soil upper boundary surface is defined with is lower soil layer's name and any point in any soil layer can be classified by looking up the immediate upper boundary surface's soil layer name, Fig. 12.

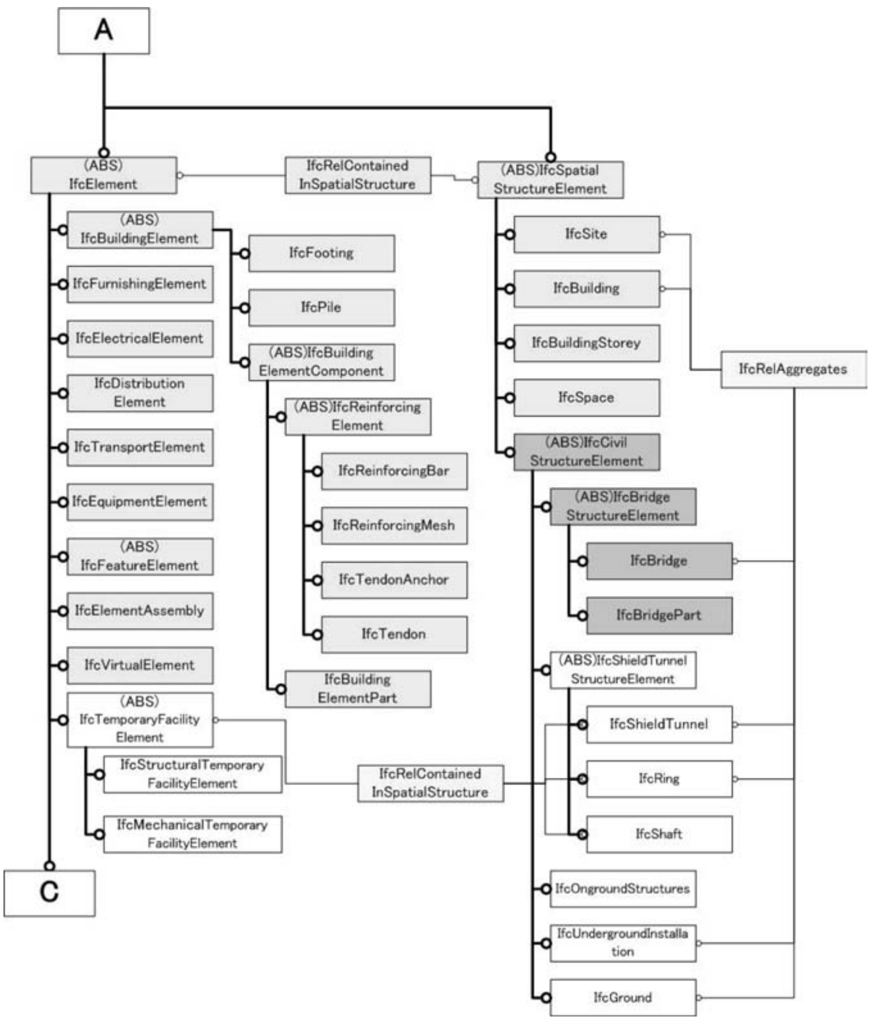


Figure 6. A part of IFC-ShieldTunnel (2).

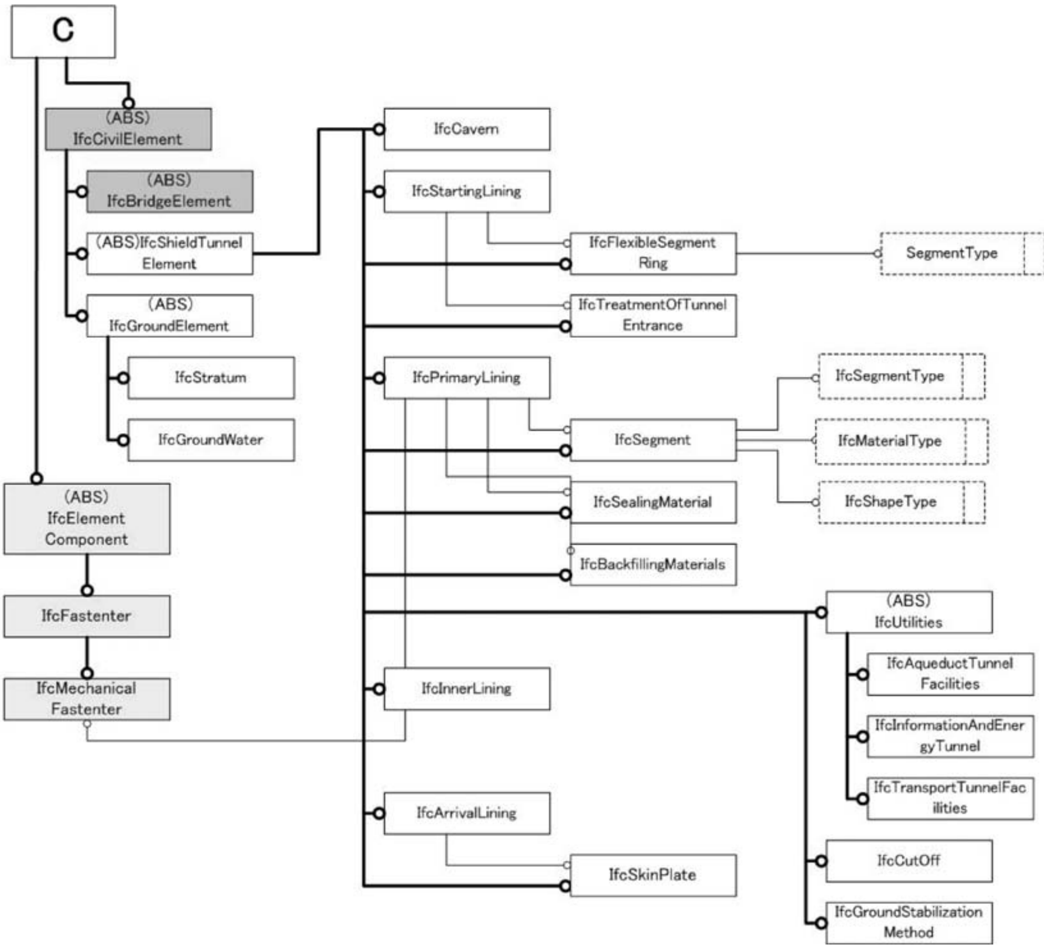


Figure 7. A part of IFC-ShieldTunnel (3).

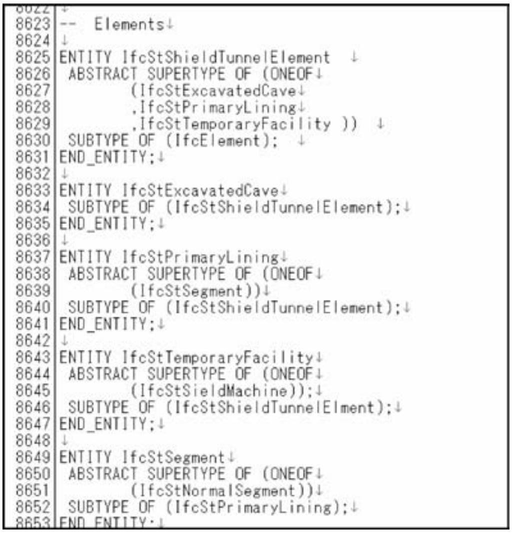
4 REPRESENTATION OF CAVES IN SOIL LAYERS

The difference between the shield tunnel product model and other existing ones such as buildings and bridges is that the former has a void made by the excavation process in solid earth, while the latter structures are constructed in an open space by adding new objects. Not so much research has been done for representing caves or caverns in ground soil layers in product models. In this research, two methods were conceived for representing caves in soil layers. One method is representing caves by a set of boundary surfaces. The other method is inserting "cave" objects into soil layers.

4.1 *Boundary surface method*

The boundary surface method defines a cave by inserting a set of soil layer and cave boundary surfaces into soil layers. In this method, soil layer surfaces are defined as *Sn*, where *S* means surface and *n* is the number of the soil layer surface, and cave boundary surfaces are defined as *Cn*, where *C* means cave and *n* is the number of the cave boundary surface. As shown in Figure 13, anything under *Sn* is the realm of soil layer *n* by the lower boundary layer, and anything under *Cn* is the realm of the cave *n* by the lower boundary layer. As shown in Figure 14, any caves, even if they are located in complicated soil layers, encompassing a number of layers, can be represented by this method.

However, this method has a drawback that it would take a long time for CAD users to define caves and that the volume of the product data model may become very large if soil layers and cave shapes are complicated. And the developed IFC-ShieldTunnel product model schema has to be modified because IfcCavern class has been defined as a sub-class of IfcShieldTunnelElement class and is separated from IfcGroundElement and IfcStratim classes in the current IFC-ShieldTunnel.



```
-- Elements

ENTITY IfcStShieldTunnelElement
 ABSTRACT SUPERTYPE OF (ONEOF
        (IfcStExcavatedCave
        ,IfcStPrimaryLining
        ,IfcStTemporaryFacility ))
 SUBTYPE OF (IfcElement);
END_ENTITY;

ENTITY IfcStExcavatedCave
 SUBTYPE OF (IfcStShieldTunnelElement);
END_ENTITY;

ENTITY IfcStPrimaryLining
 ABSTRACT SUPERTYPE OF (ONEOF
        (IfcStSegment))
 SUBTYPE OF (IfcStShieldTunnelElement);
END_ENTITY;

ENTITY IfcStTemporaryFacility
 ABSTRACT SUPERTYPE OF (ONEOF
        (IfcStSieldMachine));
 SUBTYPE OF (IfcStShieldTunnelElment);
END_ENTITY;

ENTITY IfcStSegment
 ABSTRACT SUPERTYPE OF (ONEOF
        (IfcStNormalSegment))
 SUBTYPE OF (IfcStPrimaryLining);
END_ENTITY;
```

Figure 8. A part of the IFC-ShieldTunnel schema.

```
<IfcGeometricRepresentationContext href="B1001" />
</ContextOfItems>
- <Items>
- <IfcExtrudedAreaSolid>
 - <SweptArea>
  - <IfcArbitraryClosedProfileDef>
     <ProfileType>AREA</ProfileType>
   - <OuterCurve>
    - <IfcCompositeCurve>
     - <Segments>
      - <IfcCompositeCurveSegment>
         <Transition>CONTINUOUS</Transition>
         <SameSense>FALSE</SameSense>
       - <ParentCurve>
        - <IfcPolyLine>
         - <Points>
          - <IfcCartesianPoint>
           - <Coordinates ex:cType="list">
               <IfcLengthMeasure pos="0">150</IfcLengthMeasure>
               <IfcLengthMeasure
                 pos="1">259.8076</IfcLengthMeasure>
               <IfcLengthMeasure pos="2">0</IfcLengthMeasure>
             </Coordinates>
            </IfcCartesianPoint>
          - <IfcCartesianPoint>
           - <Coordinates ex:cType="list">
               <IfcLengthMeasure pos="0">175</IfcLengthMeasure>
```

Figure 9. A part of the IFC-ShieldTunnel schema.

4.2 *Cave object method*

In the cave object method, the user inserts a cave object into soil layers. A cave object is a solid object but the semantics is "empty" and it overlaps with soil layers. Once the cave object inserted, the cave object has a priority over the overlapped soil layers and excludes the overlapped area.

This method is simple and the user can make caves by using various modeling methods, while IfcFaceBasedSurfaceModel must be used in the boundary surface method, which gives the cave object method users more freedom and ease of use.

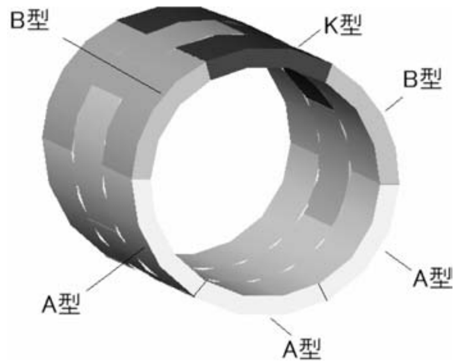


Figure 10. Segment product model data represented by using a commercial 3D CAD software.

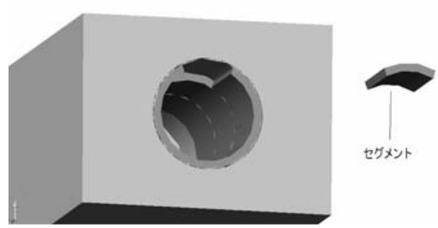


Figure 11. Segments and ground product model data.

4.3 *Implementation and comparison*

For comparing the proposed two methods, sample soil layers were implemented by using ifxXML. Soil layer surfaces were generated as triangulated irregular network (TIN) data, and Civil 3D was used for rendering and data input/modification.

As discussed above, the cave object method was found to be more flexible and easier to define and control data than the boundary surface method in the implementation and utilization tests.

5 CONCLUSION

In order to store various data related to shield tunnel design, construction, and maintenance, a conceptual shield tunnel product model was developed, and then, IFC-ShieldTunnel was developed by converting the conceptual model and expanding the existing IFC of IAI. In the development process, the problem of representation of caves in soil layers was identified. Two methods, i.e., boundary surface method and cave object method were proposed and compared. In this research, the cave object method, where caves are represented as solid objects representing emptiness, was found to be more flexible and easier to use in the test implementation.

For future work, IFC-ShieldTunnel should be modified by adding more classes and properties. Not only

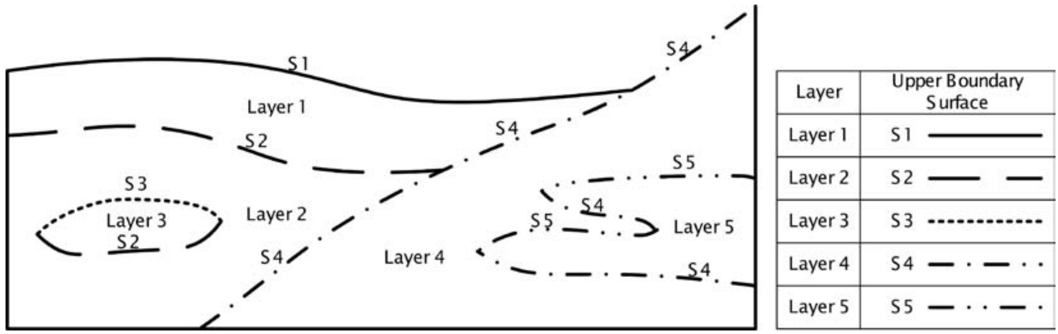


Figure 12. Soil layer representation method.

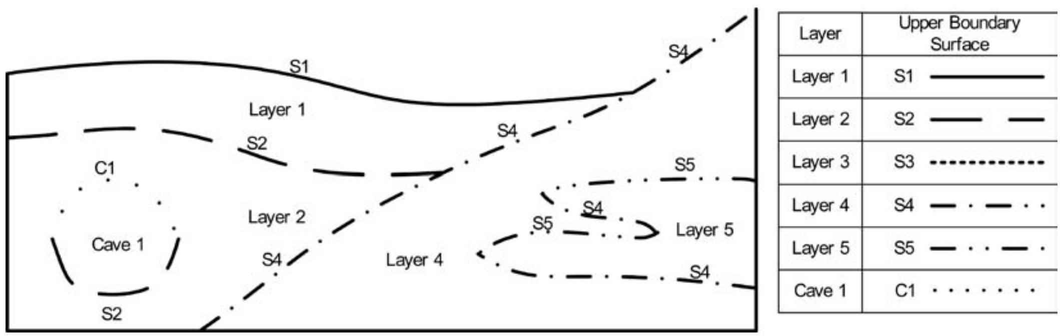


Figure 13. Boundary surface method for representing caves.

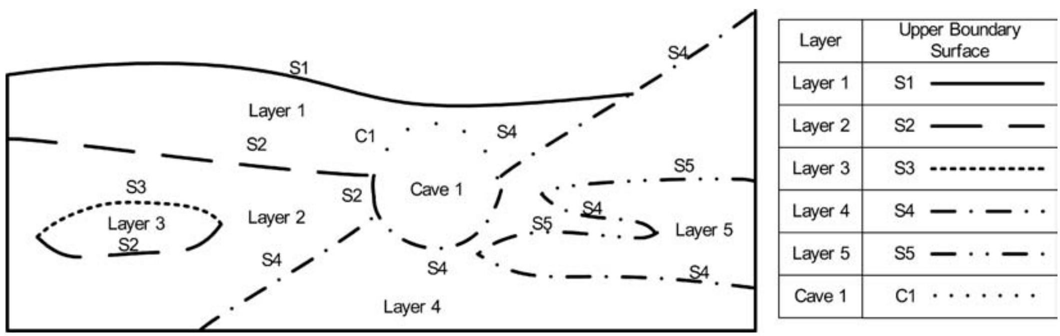


Figure 14. A cave in a complicated soil layers.

object classes but also measured data classes should be implemented for actual construction works.

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Innovative R&D in philosophical doctorates

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

4D model based automated construction activity monitoring

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ABSTRACT: Manual monitoring of building activities does not satisfy the need for information especially in case of unforeseen on-site events and conditions. Various IT based methods have been introduced, but so far none is able to deliver satisfyingly reliable information. The paper is presenting an automated activity monitoring system, which is based on image recognition by using extracts from the 4D model of the building.

1 INTRODUCTION

Accurate monitoring of construction activities is a prerequisite to detect delays, which have been recognized as the most common and costly problem encountered in construction projects (Alkass et al. 1995, Josephson & Hammarlund 1999, Levy 2002). The only solution to assure a consistent flow of relevant information seems to be automation of data collection (Kiziltas et al. 2008). Many attempts have already been made using various approaches in order to control construction project performance (Navon 2007, Kiziltas et al. 2008). They are based on indicators, like labor productivity (Stauffer & Grimson 2000, Navon & Goldschmidt 2002), use of equipment (Sacks et al. 2002), materials flow (Cheng & Chen 2002, Ergena et al. 2007), or directly measured activity progress, like some recent methods based on site image recognition (Podbreznik & Rebolj 2005, Kim & Kano 2008). Further attempts have been reported where mobile devices have been used by workers to support faster and more reliable data collection (Garrett & Sunkpho 2000, Ward et al. 2004, Bowden et al. 2005).

In our approach we have focused on activities as the main entities in the construction information loop, which includes activity plans (schedule plan, 3D model), on-site activity progress, and a comparison between both. The automated activity monitoring method is based on site images of the building, which are being compared to the 4D graphic representation of the building in the same time frame. The basic function of the monitoring system is to find the difference between planned and built elements of the building

2 AUTOMATED CONSTRUCTION ACTIVITY MONITORING SYSTEM

4D modeling has become a useful method to support various tasks in the life-cycle of a building (Koo & Fisher 2000, Chau et al. 2004, Jongeling & Olofsson 2006, Mourgues et al. 2007). 4D model contains the product and the process model and thus integrates information about geometry and about building activities. The automated activity tracking system (4D-ACT) is performing a real-time comparison between site images and images extracted from the 4D model showing the building model at the same point in time. It contains the following functional modules: the 4D tool, image segmentation, camera calibration, and building elements recognition. All modules have been tested separately on different real cases as well as together in experimental environment and in a site case study.

Construction of the 4D model is very important in our case, because the entities of the model have to be recognized visually. The 4D tool has been developed to get full control over the data structure in the 4D model (Figure 1). The most important feature of the 4D tool is the 3D reference model, which is presenting the 3D model at a defined time in the building process.

To establish the recognition process of building elements it is necessary to extract the various levels of information from the image (colors, gradient, textures etc.) for which segmentation is the most common way. The region growing (Potoènik & Zazula 2002) was chosen as the most suitable method for segmentation of noisy building site images. Segmentation process is based on finding areas of pixels with similar predefined features.

Before starting the segmentation process, the algorithm establishes criteria from a learning set. The user marks small pieces of image, which are members of the area he wants to segment. These pieces are defining the learning set. The result of segmentation is an extracted image area, which has a certain level of similarity regarding the learning set (Figure 2). In this way parts of image, which do not belong to the building (for example temporary equipment) are filtered out.

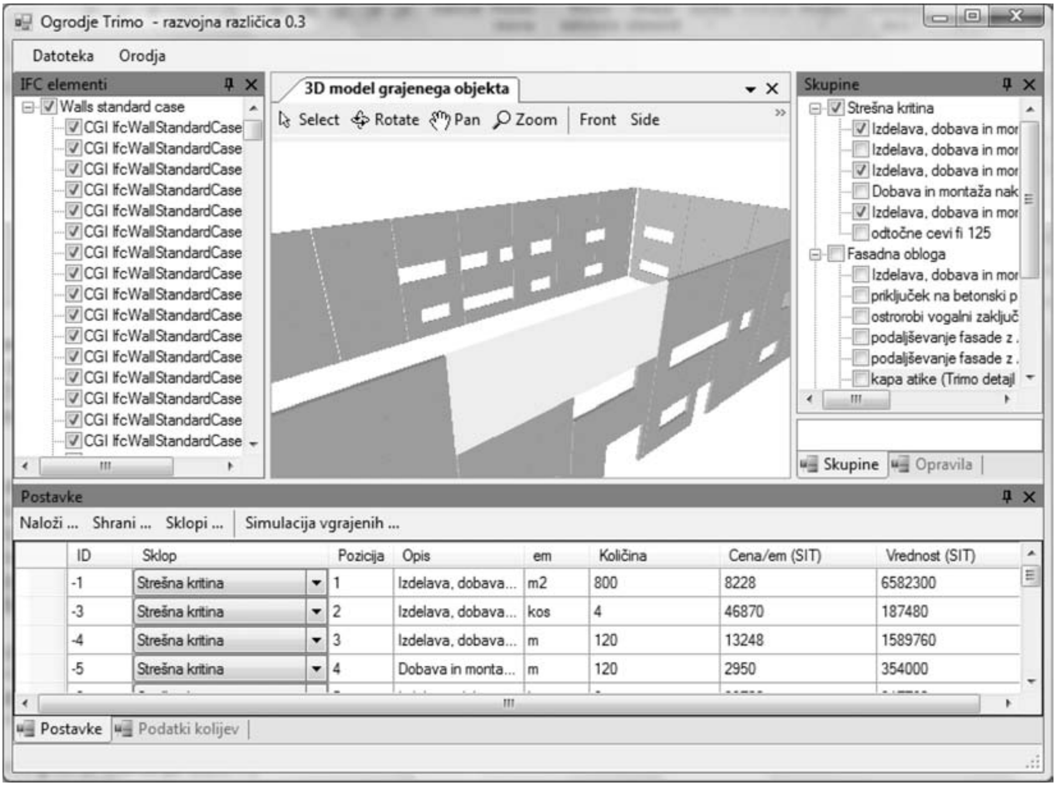

Figure 1. 4D tool enables definition of the 4D model by linking information from the product and the process model.

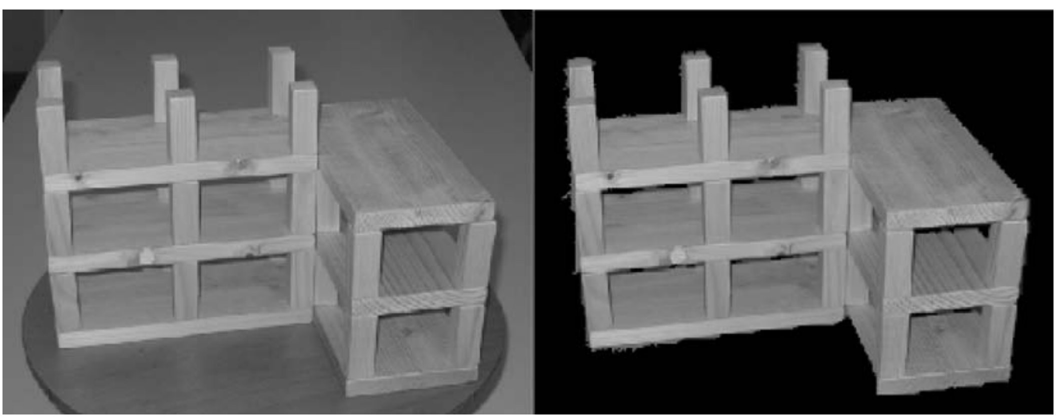

Figure 2. Input and results of the segmentation process in an experimental environment.

When a segmented shape extracted from a site image matches with a shape of the 3D reference model image then the building element is recognized rather easily. But usually parts of building objects are hidden by temporary equipment or by the building itself and thus collection of information about observed objects are not applicable.

To solve this problem the images have to be captured from multiple cameras with different positions and orientations. Merging data from multiple cameras

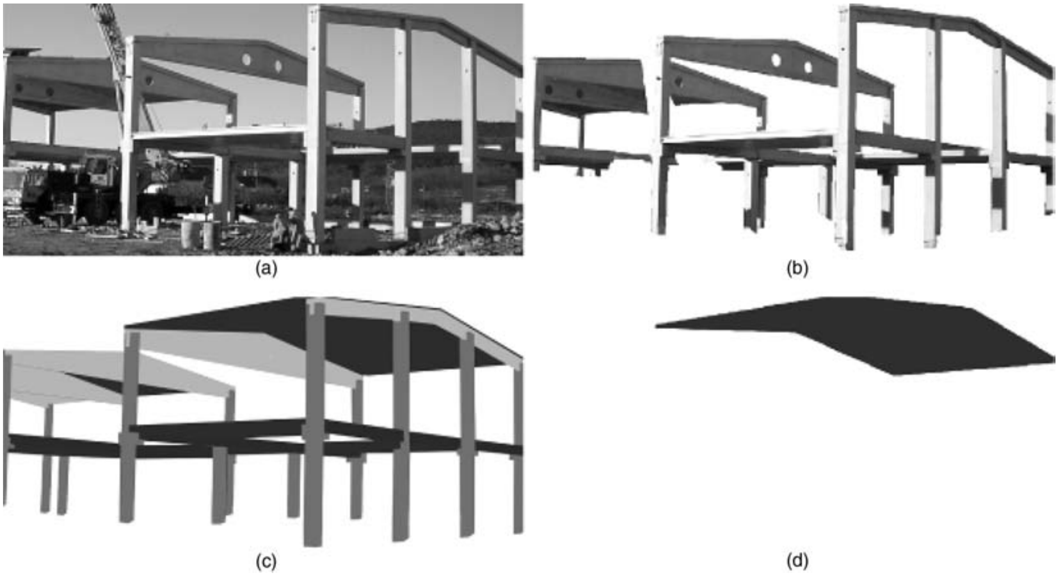

Figure 3. a) site image of the building describes as-built situation b) segmentation of the site image c) image of the 3D reference model depicts as-planned situation d) the difference between as-planned and as-built models.

is possible after they are calibrated. Calibration can be performed by various methods (Forsyth & Ponce 2002, Hartley & Zisserman 2004, Zhang 1998) like: eight-point algorithm, LMedS, RANSAC, M-estimator, etc. The M-estimator calibration method was chosen to be used in 4D-ACT.

The segmented site image and the model view image are both showing the same elements in the same perspective, considering that parameters of the virtual camera and the building site camera are same.

Comparison between the segmented site image and the model view image is done by automated recognition algorithm, which is based on minimum differences between element features from both images (Bigun 2006). If the difference is under a predefined threshold, then the element from the segmented image has the highest probability to be identified as an element from the model view image.

Different scenarios can be expected during recognition process. Successful matching of all elements from the segmented image is the best scenario and means that the learning set has been marked optimally, images from the building site were successfully segmented, and activities on-site match with planned activities. In case of unsuccessful matching 4D-ACT identifies and lists unmatched elements as either missing elements or unknown elements (intruders).

Various reliability levels of building elements recognition can be reached, depending on building complexity, camera system, building site, or building process technology. Further developing of the system will be oriented to recognize obscured building elements by using multiple cameras.

3 ON-SITE TEST

A single camera has been used to test the 4D-ACT system on a real construction site. We have intentionally chosen a construction, which is built with prefabricated elements that are easy to recognize. On Figure 3a we can see a picture taken from the camera at a specific point in time. This picture has been segmented by the segmentation module (Figure 3b) and then used together with the adequate image extracted from the 3D reference model (Figure 3c) as input for the building elements recognition module. In the presented case the module correctly identified the roof element (Figure 3d) as the difference between both images, thus the difference between the existing and planned situation. The vehicle on Figure 3a has been correctly filtered out in the segmentation process as it has not been recognized as a member of the learning set (it differs in gradient, texture and color).

4 CONCLUSION

According to the current case study the 4D-ACT system has fulfilled our expectations. So far the system has been intentionally tested under optimal conditions (weather, light and visibility, perspective, type of construction) because we have only used a single camera. Further improvements of algorithms and simultaneous use of multiple cameras integrated into a common view space should improve the overall reliability and also address problems of hidden construction elements. Activities that are performed inside building can be observed using inside cameras or even using moving cameras. There is still lot of research to be done in this area.

So far the system is only notifying the user about activity status in form of a simple list. We plan to link the monitoring system with a project management system in the next step of our research. Integration with material tracking system should further improve the reliability. Another feature of this integration will be the possibility to identify individual activities that are linked to the same BIM elements (many to many relation) according to the resources related to each activity.

Although the system does help the project and site managers in early detection of project failures regarding execution of construction activities, there is still much to be refined. Image based activity recognition (4D-ACT) has to be further developed to reach a higher level of reliability; a multiple camera should solve the problems of obscured elements. BIM technology has to be used in its full extend, but has not yet taken enough grip in the industry. In practice definitions of activities are not adequately related to BIM elements; a method of consistent activity definition has to be developed. Material resources are not always adequately related to activities, one of the reasons being in not clearly defined and identifiable units of material.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Knowledge enabled collaborative engineering in AEC

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ABSTRACT: One of the key challenges of knowledge management is to provide the applicable knowledge to the right person at the right time. Knowledge Management (KM) is now recognised as a core business concern and intellectual assets play a vital role in gaining competitive advantage. Within the AEC industries, where the drive for innovation and improved business performance requires the effective deployment and utilisation of project knowledge, such need for strategic knowledge management is also acknowledged (Kamara et al. 2002). From the point of view of KM especially targeting design and engineering domains the Knowledge Enabled Engineering (KEE) approach is a reference concept that was introduced (in part) to allow re-explore what KM represents within an Engineering context. However, KEE was not conceived with the goal of supporting synchronous collaboration for developing high-performance collaborative workspaces. This paper presents a new approach, Knowledge Enabled Collaborative Engineering (KECE), which goes beyond and complements KEE, to realise a knowledge-based solution for collaborative design and engineering. A roadmap to KECE is then drafted based upon the degree of knowledge support of the solution – Initial, Advanced and Future Workspaces – to progress towards its implementation.

1 INTRODUCTION

Nowadays companies are continuously facing new competitive situations within the knowledge economy. To addresses such increasing demand, design cycles need to be shortened, in order to cut-down on time-to-market and gain competitive advantages. It is now expected that engineers perform the design right the first time, which leads to the requirement of using the right knowledge in professional practice. Such correct identification and usage of knowledge (e.g. best design/engineering practices) enables designers and engineers to perform better and faster. Knowledge Management (KM) is thus seen as a key element of enterprises' strategies of today to cope with globalisation and dynamism of markets.

The ability to capture important information and transform it into useful knowledge is critical to the successful operation of organisations today. Recent developments in Information Technologies allow organisations to actively capture, store, analyse and retrieve information in ways that were not possible in the past. Examples of these technologies include data mining, advanced decision support tools, intranets, and decision indexing (Messner, 2003).

Various kinds of technologies and information systems have been developed and adopted for supporting KM. However, the technology alone does not offer the full solution; an extensive change is needed at behavioural, cultural and organisational levels in order to make KM successful. As knowledge creation in design and engineering domains is mainly related with tacit knowledge, and information systems are able to deal with explicit knowledge, the existing solutions are not capable of completely supporting the process.

Most of the current IT tools for KM are in fact only information management tools, in the sense that they are only able to process information. Information is however inherently different from knowledge. Knowledge requires context in order to be meaningful, and the tools are not usually sensitive to the context of knowledge and thus can only support information and basic knowledge aspects while the important tacit dimension of design and engineering knowledge is not considered. There is then an evident need for an integrated approach that takes into account the dynamic and human process of knowledge creation for developing information systems for Knowledge Management (Nonaka et al. 2001).

However, the focus within engineering solutions today is heavily biased towards information technology (IT). Organisations repeatedly look to the next 'silver bullet' IT solution to solve problems. CoSpaces Integrated Project is attempting to shift this emphasis towards a more knowledge-based approach. I.e., not to simply raise IT to become KT (Knowledge Technologies), but to consider a holistic approach that takes into account organisational structures, cultures and behaviours.

In short, any method, or approach, that improves the leverage of knowledge within the extended enterprise, comprising of customers, prime contractors and the supply chain. By shifting the focus to a knowledge enabled enterprise, benefits will be sought, such as improving lead-time by avoiding rework and "re-invention of the wheel", promoting re-use within design and bid proposals, to increase efficiency within collaborative working environment, and to reduce time needed to find information.

1.1 *Knowledge management and AEC*

Knowledge Management is especially relevant in construction, as industrial practice is intrinsically collaborative, performed within knowledge-rich multi-functional working environments. Such team-work exists in all key-phases of life-cycle: from planning, e.g. where planners interact with Public Authorities to develop zone plans; to design, e.g. where architects interact with engineers and owners to develop the construction project; to build, e.g. where many contractors for many purposes cooperate towards the goal of building the structure, and with owners to report on progress status; to facilities management, where operation & maintenance personnel rely on information made available after project conclusion, to, along with technology (ICT, ubiquitous computing and BIM) be effective and efficient in their tasks.

However, the current practice in what concerns the adoption of knowledge based approaches within the AEC sector is almost inexistent. This may be due to the fact that construction is still considered to be much closer to craftsmanship than to manufacturing, in the sense that each project is actually a prototype, which hinders knowledge collection and reuse. However, a trend exists towards a more industrialised construction (Kazi, 2006) driven by open market, JIT, site productivity and ambient manufacturing and construction.

In AEC, most information is still stored in scattered archives, mainly paper-based in few cases digital. Content is not annotated, and is extremely difficult to find. Experiences from projects are not captured or retained efficiently and in most cases reside only in the minds of those involved in the project. There is little, if any sharing or propagation of knowledge. The experience of previous activities is available in personal and departmental archives and solutions are regularly redone in every project.

It's expected to share previous experiences, best practices and knowledge within and, increasingly, between organisations. The aim is to have (transparently) immediate access to the right knowledge, at the right time, in the right format, and from the right sources (both internal to an organisation and external). The goal is to deliver the applicable knowledge to the user context in order to enhance productivity and reduce errors and rework.

This trend is fuelled by the fact that for construction projects typically no information is reused and all information is (re)invented. The idea is to split all information explicitly in project-dependent and project-independent domains where the latter functions as a kind of knowledge database covering all corporate/company knowledge. One step further is the reuse of knowledge beyond the company. Good examples are resource databases like the ones containing Supplier and Sub-contractor information.

A more technological influence is the trend to put information and/or application software not on local desktops but put them on servers (in-company or at an application server provider). This approach enables easier reuse of both data and (software) functionality. This is an aspect of another trend referred to as "Information Sharing" but this is clearly a prerequisite for processes that want to reuse knowledge.

The "project-independent" view is just one interpretation of the concept of "knowledge driven". Two other interpretations are equally relevant: (1) the reuse of past successful experience as best practices for the present and the future. This interpretation means that knowledge is seen as less fact-based and more heuristic-based; and (2) finally knowledge is often seen as a higher level form of information: knowing how to get information, who to involve, how to generate or derive, how information is interrelated and constrained etc. This interpretation involves the specification and handling of meta-information that goes beyond declarative (like rule-based) approaches and need process oriented procedures and usage of object oriented approaches.

However, there are opportunities to the construction industry ready to take up using existing technologies focusing on industry-wide collaboration between various actors rather than on issues which mainly influence internal activities of a single company only.

As ready to take up, was identified a set of basic processes for a knowledge management initiative. They are to be enabled through strategy and leadership; culture; measurement; and technology.

- Identify: Methods and tools for the identification of relevant experiences and practices that may form re-usable knowledge.
- Collect: Methods and tools for the collection of knowledge from various sources and archives (personal, organisational, inter-organisational).
- Organise: Methods and tools for knowledge systematisation and consolidation. Once knowledge has been collected, there's a need to structure it in a meaningful form for ease of extraction and use.
- Share: Methods and tools for knowledge dissemination/propagation, search and retrieval.
- Adapt: Knowledge is not necessarily always applicable in the form it is in. On most occurrences, it needs to be customised or adapted to organisational peculiarities. For this, it is necessary to have in place, o Organisational guidelines for business processes, task descriptions and the organisation of information.
- Use: Methods and tools for knowledge re-use. These help in the retrieval, adaptation and re-use of past experiences and practices.
- Create: Methods and tools to re-create knowledge (new knowledge created on the basis of existing knowledge, or use of existing knowledge) (ROADCON, 2003).

1.2 *Knowledge enabled engineering*

From the point of view of KM especially targeting design and engineering domains the KEE approach is one of reference. Knowledge Enabled Engineering (KEE) is a new concept that was introduced (in part) to allow re-explore what Knowledge Management represents within an Engineering context. As such it provides an opportunity to explore and define today's challenges, solutions, and even terminology, associated with KM for Engineering (Bylund et al, 2004).

KEE is the ongoing process through which an enterprise uses its collective knowledge to reduce the duration and improve the robustness of strategic engineering activities. KEE fundamentally means leveraging knowledge sources in order to enable engineers and designers to complete their work quickly and correctly. Thus, KEE is about providing the right information to the engineer, at the right time, in the right format, in a collaborative environment that promotes learning within the organization, across the supply chain and across the Extended Enterprise.

The purpose of KEE is to allow automation of engineering work as this creates an opportunity to extract knowledge normally found in later (downstream) phases and make this knowledge available in the conceptual phase. KEE final goal is to provide the applicable engineering knowledge depending on the user's context.

Engineering knowledge deals with knowledge about products, processes and organisations. Within engineering design knowledge from many disciplines is needed to be captured and managed. Capturing of engineering knowledge is not an easy task to perform, as the knowledge exists in a number of disciplines moving from business to maintenance activities. A key issue is that engineering knowledge is often stored in people's head or diluted with other possibly irrelevant, information in technical documents.

User context deals with any information that can be used to characterise the situation of an engineer. Such information should be represented by a relevant context model that could easily be understood by engineers. In the literature different context models were proposed, some of them, developed for context representation of mobile users focus more on describing the user's physical context (Lelouma, T. & Layaïda N. 2004) (i.e. his/her current location, device, available resources, etc.), whereas some others include the description of the user's organizational context (role, group membership, tasks, etc.) and that we can use to quickly develop a platform in order to gain the end-user buy-in.

2 KNOWLEDGE ENABLED COLLABORATIVE ENGINEERING

The KEE approach fails in the sense that it does not support the basis for synchronous collaboration. i.e., the decisional space within the KEE has not been taken into account, functionalities like storing decisions; describing and classifying issues and problems are beyond the scope of the KEE approach. Therefore, KEE should to be expanded to support enhanced collaboration within engineering project teams' trough knowledge.

Nowadays, distributed knowledge workers and teams lack proactive system support for seamless and natural collaboration on applications like problem solving, conflict resolution, knowledge sharing and receiving expert advice on-demand. Ambition is to have innovative workspaces to establish effective partnerships that are able to collaborate, that drive creativity, improve productivity, and enable to take a holistic approach to implementing product phases. Such collaborative working environments of the future will be based on enhanced communication, advanced simulation services, improved visualisation, natural interaction and especially knowledge.

Knowledge Enabled Collaborative Engineering (KECE) goes beyond KEE, to realise a knowledge-based solution to develop such innovative collaborative

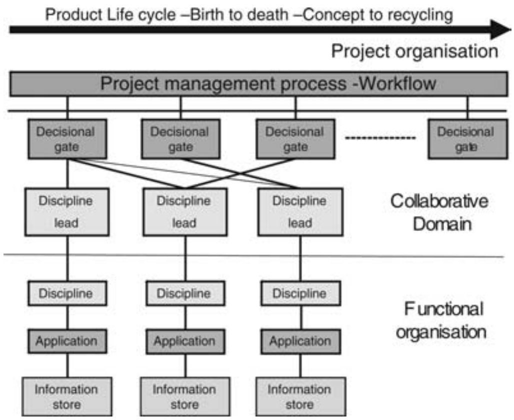

Figure 1. Nature of Industry Collaboration.

workspaces. KECE is then a complementary approach to KEE, to support synchronous collaborative engineering through knowledge.

For instance, the collaborative workspace as depicted in the figure is composed by a set of checkpoints called decisional gates where issues related to design optimization and risk analysis are taken into account. Each decisional gate is where every party in the collaboration process agrees on an approach to problem solving, supported by discipline experts. KECE presents functionalities that facilitate decision-making by providing an historical tracking of the project decisional space (issues and decisions).

2.1 *The collaboration lifecycle*

For the purpose of this work, it's assumed that collaboration is undergoing a lifecycle, during which collaborative sessions are prepared, executed and finalised by a predefined group of parties.

These sessions of active collaboration generally follow a well defined workflow. For example the tools and datasets used for weekly design review meetings will usually remain the same (the data in the sets changes, of course). Even the basic tasks will be similar, e.g. modification of parameters or geometry. Between these sessions of active collaboration the management system stores the key properties of the sessions. These can be restored when starting a new session and beginning a common workflow.

The workflow assumed for the collaboration lifecycle is described in the figure. It resembles the actions that occur repeatedly during the project. Four phases have been identified, which are described in the following.

The collaborative tasks are preceded by the individual work carried out by the participants of the project. Problems may be encountered which need to be solved collaboratively. Therefore documents describing the

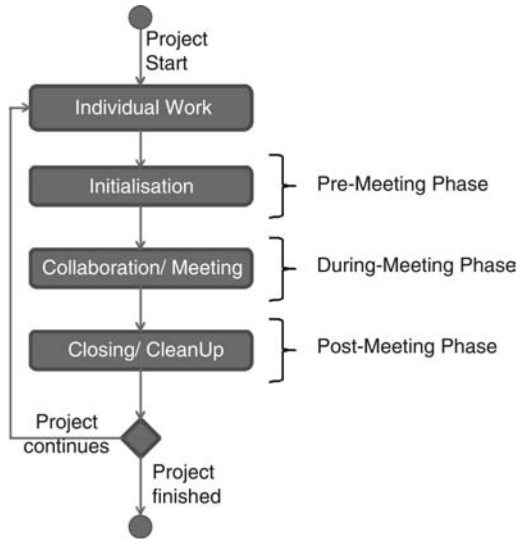

Figure 2. Overview of the Collaboration Lifecycle.

problem have to be compiled to be used during the collaborative session or to be distributed beforehand.

The second of the four phases is the initialisation. During this phase, one participant of the collaboration starts the scheduling process. This determines the date and participants and type of the collaborative session.

After the initial configuration of the session all participants need to agree on the settings. The session may be reconfigured until a common consent has been reached. Configuration includes identifying the availability of the required resources such as applications, hardware resources, rooms, experts, participants, documents like agenda, minutes of previous meetings, and decision documentation. During the next step large data, which cannot be accessed on demand over networks, is distributed to the local hosts. The applications, which now were started on the local hosts for collaboration, can access the data without large delays.

After the applications are available, the session is ready and open for the users. Subsequently collaboration between the users takes place, during which data is produced and modified. At the end of the meeting these data and a collaborative written summary can be stored. This includes minutes of the meetings, enhanced by recordings, plus documentation of decisions.

Subsequently, results will be sent to all authorized participants and the session will be closed, including all connections, applications, and processes.

3 RESEARCH APPROACH

The CoSpaces project is using scenario development, questionnaire methods, in conjunction with

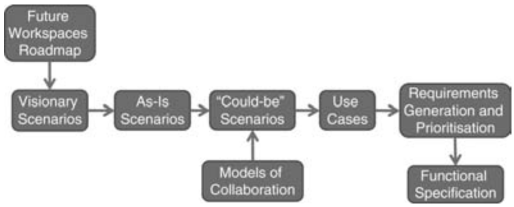

Figure 3. Research Approach.

interviews, and workshops with experts to elicit the user requirements for developing the CoSpaces technology. A number of template tools are being used to support the scenario and requirement generation processes. Workshops involving user partners and experts are been conducted to discuss requirements for collaboration and develop scenarios which define their current practices and future possibilities.

The questionnaire method, in conjunction with interviews, is being used to give the opportunity for users to better express their work duties/tasks in more depth and how they envisage they could improve their current working practices by the use of new technologies. Scenarios and use cases are drafted to focus the user requirement process and subsequently the system specification. It is important that all the stakeholders understand the importance of this process, ensuring that the end product is successful in meeting the desired goal.

The work follows an approach that guides development based on scenarios and requirement engineering for the knowledge-based system specification, as depicted in the figure below.

3.1 *Visionary scenarios*

The CoSpaces project started by the basis already developed under the Future Workspaces Roadmap which is a project (IST-2001-38346) funded by the European Commission under the Framework V programme. This project focused on the aerospace, automotive and the construction sectors and brought together large number of experts across Europe to define the 2013 European vision of collaborative engineering workspaces.

The project has not started from a tabla rasa. There were initial ideas of the form that potential applications of CoSpaces systems could take to support collaborative engineering, to varying degrees of concrete or fanciful, available through the visionary scenarios created in written, graphical and video form by key CoSpaces partners during their work on the Future Workspaces project.

Future Workspaces roadmap project (IST-2001-38346) was funded by the European Commission under the Framework V programme. This project focused on the aerospace, automotive and the construction sectors and brought together large number of experts across Europe to define the 2013 European vision of collaborative engineering workspaces.

These scenarios were used to attract new user partners and experts to the project, and to initiate early discussions between developers. These scenarios are akin to conceptual (or creativity) scenarios, that are produced by the developers and researchers to present to potential user companies and end users in order to stimulate imagination and creativity. These early scenarios enabled an extension of the vision of CoSpaces potential.

3.2 *"As-Is" scenarios*

Scenarios of current collaborative engineering work have been developed for the engineering work functions, workspaces or work processes where collaboration is used but could be improved, or is not used currently but is necessary in the future. Such a type of "as-is" scenario development is often used in the early stages of a development project in order for clients to describe more easily and richly to developers their current situations, settings and needs. These scenarios have been developed through workshops involving user partners and experts and through follow up questionnaires and interviews.

Such scenarios analysed under this work are related with:

- *Design Review*, where a team of construction stakeholders comes together to discuss the design a toilet for disabled people. Due to ventilation and elevator needs, the space left for toilet is no longer the same as the prescribed dimensions. During the review, various concepts, configurations, contamination issues and impact on other design elements need to be tested; and
- *Site Supervision*, where one of the sub-contractors faces a constructability problem (not enough space for a ventilation tube) since it clashes with previously installed services. Relevant stakeholders need to be brought together to agree on a solution.

3.3 *"Could-be" scenarios*

The next stage is to participatively adapt the scenarios from descriptions of current collaborative engineering into the possible future with CoSpaces technologies. These are termed "could-be" scenarios and lie somewhere between the conceptual and concrete scenarios. The generation of these "could be" scenarios will be further enhanced as the CoSpaces technology begins to deliver solutions over time. In addition to the user partners in the CoSpaces project, external companies and experts in the collaborative engineering domain have been invited to support the generation of such "could-be" scenarios and to provide feedback on the CoSpaces technology.

3.4 *Use cases*

At this stage, a set of specific use cases were developed describing the actors, the actors' goals in using the CoSpaces system at a particular time and place, interaction between actors and devices, simulation and data needs etc. There are several alterative use cases for each scenario, and in some situations the use cases may be written as task sequences in a graphical form.

3.5 *Requirements generation and prioritisation*

The "could-be" scenarios and the use cases were used to define the user requirements for the collaborative workspaces. In particular, this process will extract user requirements for the knowledge support technical theme for guiding the development of the collaborative software framework. This will entail a substantial exercise in negotiation and prioritisation, between what users want and developers feel is possible, between requirements of different user partners, and even about which scenarios to implement.

3.6 *System specification*

Once the user requirements have been agreed, they will be translated into system specifications to support CoSpaces systems development.

4 DESIGN REVIEW SCENARIO

The scenario of collaborative work has been developed for the engineering work functions, workspaces or work processes where collaboration is used but could be improved, or is not used currently but is necessary in the future. Such scenario to be analysed under this work is related with design review, where a team of construction stakeholders comes together to discuss the design a toilet for disabled people. Due to ventilation and elevator needs, the space left for toilet is no longer the same as the prescribed dimensions. During the review, various concepts, configurations, contamination issues and impact on other design elements need to be tested.

As described earlier in the previous section, one of the CoSpaces scenario deals with a problem related with a space that was originally designed to be a disabled toilet has been reduced in floor area due to a new requirement. A co-located meeting is required to redesign the space.

It's intended to be tackled by the scenario, the design change processes, the technology available and the people's interaction.

During design phase, a problem was identified. A space that was originally designed to be a disabled toilet has been reduced in floor area. There is a need to include a separate installation shaft to a ventilation system due to a new requirement. The toilet has therefore needed to be redesigned. Design must still include similar elements as previously planned. Meeting required.

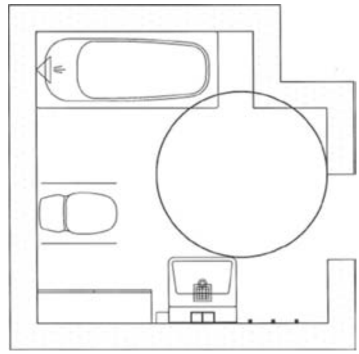

Figure 4. Co-Located Scenario.

The objective of the proposed scenario is to make the meetings more effective, which means that there is a better shared understanding between the participants, that more view points can be considered and agreements and be resolved much faster. In order to achieve this, useful information has to be made available faster between all the participants independently of the location, in a way that is easily understood by the people who need it. As a consequence, fewer meetings are required due to incomplete agreements, fewer problems have to be solved and the possibility of redesign as well as testing alternative solutions during the meeting. This speeds up the building construction and makes the collaborators more easily available for fast responses in case their expertise is required for minor issues.

4.1 *Pre-meeting*

The preparation of the meeting starts by the project manager inviting the relevant stakeholders to the collaborative workspace that is to be used for project meetings. Using the Virtual Organisation calendar to check the availability of the stakeholders that should join the meeting and proposing three dates when everyone seemed to be available. The system then sends an email to all the relevant collaborators to receive their confirmation. The same day, all the stakeholders confirm their availability and the meeting room is booked.

Later, a draft of an agenda is produced by the project manager and sent through the shared workspace to all the participants. Based on that agenda, the participants start by selecting the tools they would need during the meeting and link the documents and data to the shared workspace. They are helped in this task by a context aware system that pre-selects some resources based on the roles of the users and their history. Each

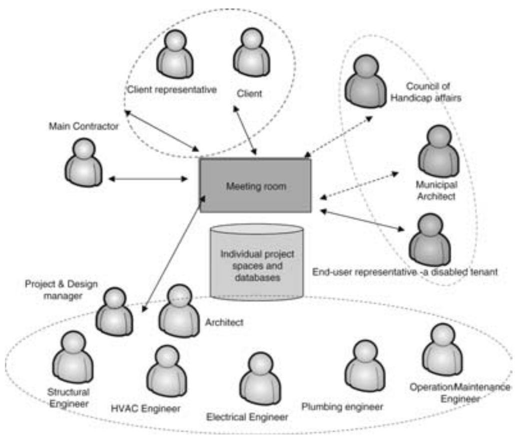

Figure 5. The meeting participants.

user defines access rights to the resources placed in the shared work-space.

4.2 *During meeting*

During the meeting phase, the project manager starts with a presentation of the problem and some alternative design solutions. During the presentation, the architect annotates 3D representations of the toilet. The annotations include information on construction specifications, selected materials, colours, surfaces and installations.

After the presentation, the participants study the designs proposed by the architect. They can annotate the models, move elements around, and share their comments with others participants as they wish. They can access documents in the shared workspace and copy some parts of them in their private 3D model. Each piece of information added in the shared workspace is associated with the building model. All the participants are linked together through the shared workspace, so that they can have small group discussions through their workspaces. During these discussions, participants can share a view of their private screens and documents with each others.

Once the participants have finished studying and populating the design examples, they explain their ideas and concerns to the group. This information is shared with each relevant participant according to his role or to possible clashes with his work. Then, the previous design propositions are redesigned with the participation of all the collaborators.

In the next phase of the meeting, a disabled person tests the accessibility of the toilets thanks to a real-size virtual representation.

4.3 *Post-meeting*

The meeting ends with the definitive validation of the design, and the participants can return to their everyday work. Minutes of the meeting are produced by the project manager, based on the structure automatically proposed by the system. Indeed, the discussions and decisions made have been recorded and classified by themes during the meeting. As agreed at the end of the meeting, this information will be held for future analysis if contextual information is needed to explain the background of change. This will also give some information about the evolution process of the meetings. The minutes are then sent to the participants, who can populate them and continue sharing information on the shared workspace for two weeks before the meeting minutes are closed and no update is possible.

Table 1. KECE Roadmap.

Phase I Initial Workspaces	Phase II Advanced Workspaces	Phase III Future Workspaces
1. Pre-Meeting		
Manual Agenda preparation	Manual agenda & automated selection of attendees	Knowledge support agenda preparation
2. During Meeting		
Manual agenda item selection	Tag/annotate audio/video records	Store decision
3. Post-Meeting		
Manual Minutes	Manual minutes with decision context analysis	Semi-automated minutes

5 KECE ROADMAP

A roadmap to KECE has been defined based on the establishment of a set of milestones, focusing on the level of knowledge support provided in the collaborative workspaces. These have been defined in three stages: Initial, Advanced and Future workspaces.

The Initial phase has a short term span and comprehends the basic set of features which guarantee a minimum level of operationally for meeting support. The Advanced phase is a medium term goal to automate some of the functionalities implemented in the basic phase. The Future workspaces solution implements the full knowledge based approach for collaborative design and engineering.

The table bellow shows the overall implementation strategy and milestones in developing the technological solutions for supporting knowledge enabled collaborative working in design and engineering domains. This is analysed following the three reference stages of the collaboration lifecycle – pre-meeting, during-meeting and post-meeting.

5.1 *Initial workspaces*

The first milestone is focused on building solutions which implement the core functionalities to drive a basic meeting thus supporting the so-called initial workspaces.

During this phase, it's supposed to implement a set of basic tools to help the meeting organizer in preparing an agenda for the meeting. This agenda preparation is done by the meeting organizer, and also the selection and invitation of attendees are performed manually.

The meeting organizer is supposed to determine the purpose of the meeting and the problems to be solved. This information should be described into the agenda to be distributed to all attendees.

During the agenda preparation the meeting organizer is supposed to describe all the topics to be discussed during the meeting. If necessary, adding links to external documentation to be used in the meeting. A problem is classified as an item on the agenda.

The way and order of the topics to be addressed during the meeting, is supposed to be conducted manually by the meeting chair. All annotations to decisions are stored in text documents. There's a need to have a minute's taker in this kind of collaborative workspace.

Finally, in the post-meting stage the meeting organizer is supposed to write the minutes based on the annotations taken during the meeting.

5.2 *Advanced workspaces*

This phase implements additional services to realise an advanced meeting support. Some of the functionalities developed in the previous phase, are here intended to be semi-automated.

At this stage, the meeting preparation uses a set of services which automatically suggests the most suitable candidates to attend the meeting. This automated functionality takes into account the disciplines and issues to be discussed at the meeting. Based on the agenda topics, the services will search on the contacts stored in the system.

During meeting, people try to understand the problems and find communalities among them. They argue on possible solutions for each problem by an interactive process. A decision is then taken.

All decisions and clarifications need to be stored in a proper electronic format. The advanced workspace implements services to record the meeting in audio format, which could be easily processed afterwards for the minute's preparation. It was considered the possibility to tag/annotate the audio file into several segments, where each of part would correspond to a specific topic in the agenda. This functionality would better facilitate the indexing and searching of a particular decision that was taken during meeting.

After the meeting ends, the minutes taker, is supposed to use the audio recorded during the meeting to start filling up the minutes and generate the final document. As an enhancement, it's planed to implement a reporting feature that quantifies/qualifies the actual involvement of stakeholders in the decision process, e.g. based on the time a stakeholder has been interacting in a discussion, pitch of voice, etc.

5.3 *Future workspaces*

The third and last phase of the KECE roadmap entitled future workspaces envisages a full knowledge-based meeting support. Here, the knowledge dimension will be used to pro-actively prepare, conduct and finalise the collaborative engagement.

The pre-meeting agenda preparation is supported by knowledge functionalities which will help the meeting organizer by suggesting a pre-defined outline for the agenda. Such template is presented, based on the set of issues that were identified during the project life-cycle. This issues map to agenda topics to be discussed during the meeting. After the generation of the meeting template, the meeting organizer can adjust the contents that were automatically generated and produce the actual agenda.

During the meeting phase, some of the functionalities addressed by future workspaces will support the storage and contextualisation of decisions tackled during meeting. Such decisions could be linked with additional documents and are stored and contextualised in the collaboration workspace repository.

The after meeting process is basically related with the minute's preparation. Taking the agenda, the system would propose a template divided in topics based on the decisions that have been discussed during meeting with additional links to external documentation that was used under discussion inside the meeting. The minute's taker is supposed to complement the document using the annotated recorded audio and issue the final minutes of the meeting.

6 CONCLUSIONS

In this paper, we outlined an approach to integrate knowledge management with collaborative engineering activities.

The KM is of extremely importance within the construction sector, as industrial practice is intrinsically collaborative, performed within knowledge-rich multi-functional working environments. It was then, introduced the KEE as a reference approach in design and engineering domains which allow to re-explore what KM represents within the engineering context.

We envisage that, a new approach which enables the basis for synchronous collaboration should be supported by enhancing collaboration within engineering project teams' through knowledge. The KECE approach, allows storing decisional context and building upon a collaborative working environment supported on a knowledge dimension. KECE also supports meeting life-cycle on all phases.

A research approach towards a knowledge-based system specification and a possible scenario of application in construction were also presented.

Finally, a roadmap describing the phases of implementation of the KECE approach was also presented. We consider that KECE goes beyond KEE, to realise a knowledge-based solution to develop innovative collaborative workspaces. Our future work involves implementing a prototype of the KECE approach and testing if for a construction project scenario.

ACKNOWLEDGMENTS

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A method for maintenance plan arbitration in buildings facilities management

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ABSTRACT: Building facility managers have to face many complex decision-making situations. One of them is the maintenance plan arbitration in buildings facilities management. The risk approach can be an efficient solution because of its ability to handle the complexity and uncertainties. The key point is then, to be able to propose a method considering risks, and adaptive to the specific context of building facility management. Our method considers traditional criteria (urgency, cost, etc.) and enriches them by criteria from risk domains (safety, technical preservation, client satisfaction, etc.). It proposes an ergonomic arbitration system based on filters mixing two complementary approaches: a selection of the fundamental actions and an optimization of the plan in a global view. The aim is to help the decision-makers build their own solution by testing multiple angles of vision in simulation logic with the support of an integrated software.

This article presents the principles of the method, illustrated by an example of a real case conducted for a leading French company.

1 INTRODUCTION

Facility management for buildings consists of "anticipating, adapting and providing the resources needed by activities, and make them available in the best conditions of security, use, overall cost and comfort." (Bonetto & Sauce 2006). It is a complex domain (Rosenfeld & Shohet 1999), with a large number of actors, crossing time and space scales and in which decision-makings are numerous and choices can have important (human, economic, etc.) and lasting consequences (important inertia of the buildings). Making decision in this context can be delicate. Numerous tools and methods are emerged to help the decision-maker, notably to draw up a maintenance plan, for example the method proposed by Johnson & Wyatt (1999). But very few of them have considered the uncertainties and the diversity of interests. By taking this multiplicity into account, we could get closer to the reality, but in the same time we increase the complexity of the problem. Risk management has developed lots of methods for the decision making in this uncertainty context. But research work (Akintoye & MacLeod 1997) has shown that in practice, few of them are used, particularly in the construction domain. There are different reasons for this, difference of culture between economic and technical domain, misinterpretation of the risk analysis approach (Ho & Pike 1994), lack of training, complexity of tools, weak equivalence with practical realities, opacity methods... Closer to a technical view, relying on their technical knowledge, the professionals involved in building facility management master only few risk concepts and mainly associate risk satisfaction with conformity to regulations.

Thus, integrating risk management elements into building facility management will first imply developing simplified methods, close to the culture but involving most of the risk experts specialized in facility management.

With this article, we propose the basis of a method designed to arbitrate actions in a maintenance plan by adopting a risk perspective adapted to the facility management context. Risk is viewed in its more general meaning, considering negative and positive aspects (Holton 2004) regarding human, financial, technical and environmental aspects. It will focus on the arbitration phase, but arbitration and assessment are linked, so these two points will be discussed. The realization phase and the monitoring phase will not be studied in this article.

Figure 1. Building facility management activities.

In order to illustrate the implementation of the method, we will give you an example of a leading French company, based on its experience.

2 RISKS IN BUILDING FACILITY MANAGEMENT

2.1 *The place of risk*

Building facility management is composed of various activities (Figure 1). Each of them follows specific procedures and builds specific process cycles. Although, each activity is hardly linked to others, every specialist uses his own adapted tools (method, software, etc.), which are efficient in its own field.

Risk management takes place at the interface of these different activities. Most of the dedicated softwares consider risks, but only at the margin. None of them place them at the center of the process. Then, the risk management is not considered from every angle, but only from one side.

So we propose to develop a new approach centered on risks to pilot facility management for buildings. This new approach imposes new methods, new tools, and new softwares. Firstly we have to analyze how risks can be integrated in the decision process.

2.2 *Management duality: Project versus risk*

One of the problems of risk logic in building facility management is the discordance of central objects. Risk management is focused on the consequences of actions, in terms of loss or gain (risk approach), while facility management for buildings focuses on the actions themselves (project approach). It is therefore necessary to find a new approach to combine the risk logic with the project approach.

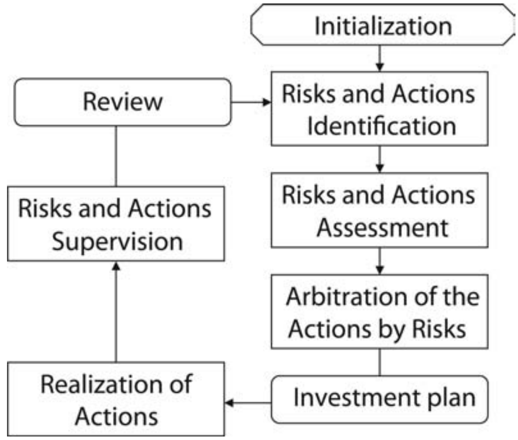

Figure 2. Mixed Approach.

The idea is to carry out a synthesis which allows us to elaborate a complete plan, integrating the diversity of actions, their causes, consequences and uncertainties, according to resource limitations and constraints (in terms of economy, delays, capacities, etc.). The concept of urgency used to assess whether an action plan is needed, is considered as one of the many facets of the risk. The urgency comes in a variety of areas: urgent need for conformity according to the regulations, for people security, asset value depreciation, etc., and urgent need to guarantee companies' production. We can notice that the notion of urgency corresponds to the notion of risks covering various aspects: regulations, operation, security of people and assets, etc. This notion can then be extrapolated to cover the whole dimension of the risk. Instead of considering only the urgency of the present situation, we can also consider the urgency of future situations.

This approach can be better understood by the various participants. On the one hand, specialists make every effort, as far as risk analysis is concerned, to disseminate not only the results, but also the consequences, the potential loss in future evolution, the gain associated with the proposed actions, in a simplified way. On the other hand, decision-makers will integrate this additional complexity into their traditional model.

The pure risk approach always rests on the responsibility of the specialist. The manager includes new risk characteristics for qualifying actions, which are integrated into its usual decision process, but in multi-criteria logic.

Then, it would be easier to implement this kind of approach rather than a complete theoretical risk approach. Moreover, it is closer to our objectives (investment plan elaboration) by placing the actions in the center of the process, enriched by the concept of risk, which will be one of the elements of the decision.

Figure 3. Devising an investment plan.

3 PRINCIPLES OF THE METHOD

3.1 *Principles*

Our method of investment plan elaboration is based on risk logic. We will therefore use tools from risk management, but we will adapt them to the domain of building facility management and to our issue. We have to recall that our article will concentrate on the analysis phase (valuation and arbitration) of the global approach of investment management.

3.2 *Identifying risks and actions*

3.2.1 *Principle*

The identification phase has a key role in the total risk management process. It is a critical phase that has an impact on the outcome of the approach and must be placed at the center of the decision making process (Adams & Martin 1982). It must lean on twofold knowledge: risk sources and affected object (building, equipment, etc.). We can define risk source as "an activity, a condition, an energy or an agent potentially causing unwanted consequences and/or effects" and affected object as "the exposed humans, environments and/or physical objects" (Christensen 2003).

Therefore, in terms of facility management domain, the person in charge of identifying risks must have a very good knowledge of the real assets and of the sources of danger.

This phase is generally taken over by specialists, operating each in their own field of expertise. You can hardly find people that benefit from sufficient technical skills in all the fields covered by civil engineering. Then the involvement of a panel of specialists is required. Each of them would have to define the risks in their own domain, which is generally a technical domain (structures, electricity, etc.).

Table 1. Number of actions by technical items.

Technical items	Number of actions	Amount (M€)
Electricity	21	3.2
Climatic comfort	52	5.5
Building structure	21	3.9
Fire Safety	12	0.1
Road	28	3.1

3.2.2 *Example*

The example developed throughout this article results from an application of the method. The purpose of this experimentation was to draw up an investment plan for a big French company. The investments concerned the maintenance of the real assets. They supported various activities, resulting in a wide variety of risks and therefore of proposed actions. The decision relating to the distribution of the dedicated budget is thus made complex, hence the use of decision tools.

To reduce the various risks, a total of 106 businesses were proposed for a total amount of 15.8 million euros. The actions were proposed by different specialists and are divided up into 5 technical items.

The budget allocated to the investment plan was 10 million euros for 5 years (then 2 million euros per year).

3.3 *Assessing risks and actions*

Actions and related risks have to be assessed according to a common system in order for them to be clearly identified and differentiated. The assessment of the actions is based on a certain number of qualifying fields. It is the decision-maker's responsibility to determine these fields because he is the only one to know the risk aspects that will be meaningful in his strategy. Each specialist has to assess these fields, i.e. to express their own results of risk analysis according to the common system defined by the decision-maker.

As regards action assessment, as a first experiment for the company, we opted for a simplified method by limiting and clearly characterizing the fields. Then, we made sure that those would be properly filled in by the various specialists.

Three different types are represented in these fields:

- Descriptive characteristics
- Required resources
- Risk domains

3.3.1 *Descriptive fields*

The descriptive fields include every piece of information provided to describe the actions. These fields can vary according to the company's organization and to the facility management function.

The following information is usually made available:

- Action number
- Action name
- Relevant technical item
- Person in charge of the action
- Building concerned by the action

3.3.2 *Required resources*

These fields represent what will be needed for the actions to be conducted. The most fundamental field is the action cost. But other fields can also be used such as the duration, the human or material resources, etc.

3.3.3 *Risk domains*

Theoretically, these fields describe the risk to which the action responded and the expected efficacy of this action on this risk. The classic risk assessment involves uncertainty, through the probability of occurrence of the risk and its consequences. It is given by the Kirkwood's formula: $\text{Risk} = \text{probability} \times \text{harm severity}$ (Kirkwood 1994).

But if the harm severity and more generally the likely consequences are well received by decision-makers and experts, it is often quite different for probabilities. Probabilities are often not well perceived by technical managers and technicians. The latter regard these notions as being too mathematical, too difficult to assess, especially for very low probabilities (which are common in the field of construction). They find it hard to define their physical meaning (Faber & Stewart 2003).

Likewise, decision-makers are somewhat impervious to probability estimation (March & Shapira 1991). They are usually more interested in the consequences than in the probabilities of occurrence.

Moreover, obtaining probability values requires that a specific task be set up in a company, based on feedback practice. However, the result of this task cannot be obtained in the short or medium term, so the company cannot wait for this result to introduce risk in its management process.

Then, we chose a simplified system of probability integrated with the consequences. The specialists have to assess features called potential damage. A potential damage corresponds to the likely consequences of the unintended event (UE) on the various consequence domains. An unintended event corresponds to "malfunctions likely to cause unintended effects on the individual, the population, the ecosystem, or the installation. They come from, and apply to the structure, the activity, the evolution of natural and artificial systems"

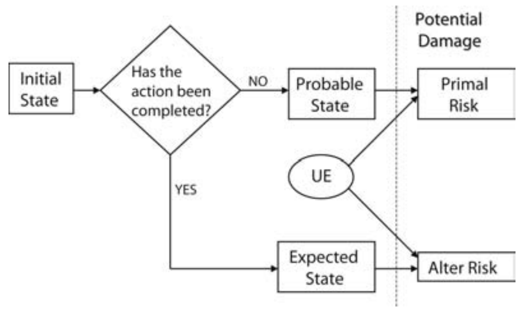

Figure 4. Notion of potential damage.

(Périlhon 1999). A common notation system is used to assess the potential damage. We identify two types of potential damage: the potential damage without action and the potential damage after action.

The potential damage without action corresponds to the consequences that may occur (it is likely to happen) if no action is to be conducted. It qualifies the risk and the urgency.

The potential damage after action corresponds to the likely consequences that may occur, once the action has been completed. This allows us to determine the action effect and then its gain.

By action efficiency is meant the difference between the potential damage without action and the potential damage after action. By action return is meant the efficiency ratio against action cost.

Figure 4 describes this notion. We can note that a comprehensive approach to risks would allow us to assess the potential consequences of the present state of an asset. In our first simplified approach, they are merged with the potential damage without action.

Then the question arises as to how to assess the consequences. The simplest way is to quantify them financially, which allows us to put the financial cost and the efficiency of actions at the same level. Some widely used methods are based on this kind of representation (the most popular one being the Cost-Benefit Analysis (Tevfik 1996)), but the fact of using the economic criterion alone gives rise to problems, among which loss of information is to be mentioned. Converting every data into a monetary equivalent data system does not make it possible for decision-makers to put the different kinds of consequences (human, commercial, material, etc.) in perspective. Another problem lies in assessing the values of cost and profit. Several studies have confirmed that costs (Flyvbjerg et al. 2002) and profits (Flyvbjerg et al. 2005) were often badly assessed, thus distorting the whole study.

The use of a multi-criteria decision system rather than a single-criterion system can be justified by different arguments. Bouyssou (1993) expressed three main arguments. The first one is the possibility of highlighting "signification axes" (a term borrowed from Roy (1985)) that are concrete, common to different participants, around which they justify, transform and argue their preferences. The second one is how to manage, at the level of each signification axis, the elements of uncertainty, imprecision, deficient definition affecting the "data" of the problem. The last argument is how to clarify the concept of compromise behind every decision.

We will therefore choose a multi-criteria approach, thus distinguishing between different domains of consequences upon which they are to be assessed. Distinguishing between areas of consequences allows us to consider risk complexity and its multiplicity. This is an important point which depends on the real context (type of asset, supported activity, facility management practice, etc.) and on the limits that we would like to set in terms of risk strategy. There is no limit on the number of domains of consequences that can be used, but the greater the number is, the more complex the arbitration phase. In fact, the real difficulty with the complexity does not come from the methods or tools used, but beyond a certain number of analysis axes, the decision-maker is not able to visualize the whole problem any more. Referring to an axis number ranging from 2 to 6 is highly recommended to avoid any possible complex problem.

In our first experimentation, we have defined three risk domains allowing us to take into account the diversity of the predictable consequences of the risks and the actions.

- Regulatory compliance: Conformity to laws and standards
- Asset value: Proper functioning of the facility
- Customer satisfaction: Compliance with the customer's service contract

The potential damage is thus represented by six fields:

- Potential damage without action at the regulatory compliance level
- Potential damage without action at the asset development level
- Potential damage without action at the client satisfaction level
- Potential damage after action at the regulatory compliance level
- Potential damage after action at the asset development level
- Potential damage after action at the client satisfaction level

3.3.4 *Qualifying Grid*

The assessment of the damage potentials for the different issues will be based on qualifying grids, a reference needed to clarify the conditions for assigning each note. These grids have a two-fold objective. They must facilitate the grading by specialists and they must at the same time ensure maximum homogeneity between the different assessments and overall cohesion.

We developed grids according to the three domains of consequences. These grids provide scores ranging from 1 to 4.

Example of a grid: Asset development
Note 1: The object concerned is unavailable
The object concerned is in such a state that it can no longer support the activities it was intended for.

Note 2: Deteriorated usage (or likely to deteriorate over time)
The object concerned can be used, but not under proper conditions. Its functioning is limited or made temporarily normal using palliative measures.

Note 3: Normal functioning
The object concerned functions normally. It is perfectly suited to support the activities and functions expected.

Note 4: Upper enhancement
The object concerned is perfectly adapted to offer capacities in excess of those needed to support the activity.

3.3.5 *End results*

Eventually, an action will be classified according to 12 fields, at least. These fields describe the main characteristics of the actions and those elements that will

Table 2. Qualification fields.

Type	Name of the fields	Nature of the data
Descriptive	Action identifier	Numerical
	Action wording	Text
	Technical item	Text (lists)
	Person in charge of the action	Text (lists)
	Building concerned by the action	Text (lists)
Resources	Financial cost	Numerical
Risk domain	Potential damage without action at regulatory compliance level	Numerical (1 to 4)
	Potential damage without action at asset development level	
	Potential damage without action at client satisfaction level	
	Potential damage after action at regulatory compliance level	
	Potential damage after action at development level	
	Potential damage after action at client satisfaction level	

Table 3. Example of assessment of an action.

Action Identifier		231569
Wording		Bringing exchangers and valves into conformity
Item		CC
Building		ZIN
Person responsible		M. Martin
Cost (k€)		360
Potential damage	Regulatory	2
without action	Asset	3
	Client	3
Potential damage	Regulatory	4
after action	Asset	3
	Client	3

allow us to measure their relevance and feasibility. Therefore, they will support the decision.

In accordance with these instructions, "method office" assessed the 106 businesses in order to arbitrate them. The following table represents an extract from this task.

3.4 *Arbitration between actions*

3.4.1 *Methods of multi-criteria decision-making*

When faced with a problem of multi-criteria decision-making, several types of arbitration methods may be used. Roy (1985) proposes a classification according to 3 categories: The first one is the single synthesis criterion (that does not manage incompatibilities), the second one is the synthesis outranking (that manages incompatibilities) and the last one is the interactive judgment with test-error iteration.

The first approach suggests using a single function by aggregating the calculated preferences on each attribute. The objective is then to optimize this function. The research work by Karydas and Gifun (2006) on the priorization of infrastructure renewal projects is part of this category. They use functions of disutility (function of utility used for feared losses) that they aggregate with an additive formula. A weighting system allows them to take into account the relative importance of the different attributes.

This kind of method gives rise to three problems. The first one is a problem of commensurability (Ben Mena 2000). Each criterion must be given in a comparable scale. This difficulty can be overcome by using a standardized utility (Brauers 2007). But reducing all criteria to a single total score brings about another default. It leads the decision-maker to consider the aggregated value alone, forgetting the diversity of the case that is combined into one single total score. The score details are then masked by the total note. The third problem is the assigning of the weight. It is extremely difficult for the decision-maker to determine weights for the different criteria that are coherent and conform truly to his will (Sefiane & Senechal 2007). Different methods allow to help the decision-maker in that operation (Marques Pereira & Ribeiro 2003). But they are generally complex and it can be very difficult to use them.

The second approach (synthesis outranking) aims first at defining some relations of outranking in order to represent the decision-makers' preferences. There are different kinds of outranking relations depending on the method. From these relations, the decision-maker can work out a solution according to his problem. A classic method of this type is the ELECTRE method (Roy 1968). It allows us to overcome the problems of criteria incompatibility and solves the weight problem partly, using an outranking process. Nevertheless, it does not solve the weighting problem completely and cannot fully compensate for a lack of clarity of the result (Ben Mena 2000). The system of aggregation can be difficult to justify because it is indirect.

The third approach uses the two first ones. It consists of devising a preliminary solution and of comparing it with other possible solutions to determine the best one. This approach uses an exchange between the method and the decision-maker that must assess the relevance of the solutions. The process stops once the decision-maker is satisfied with the solution. Most of the methods based on this approach use computerized systems to allow us to rapidly execute the iterations. The problem is the complexity which the exchange with the decision-maker implies (Ben Mena 2000).

3.4.2 *Principle of our method*

In our method, we chose a solution using the three approaches. The objective was to let the decision-maker devise his own solution by means of an ergonomic and dynamic interface. The principle is based on a simulation approach (the decision-maker will compare different options envisaged). The idea is not to just compare different solutions already entirely worked out, but to compare some partial solutions. In fact, the decision-maker will have sorting functions (filters) that will select actions. He can at any time compare the use of different filters, in order to acquire a multi-dimensional vision of the problem. The principle of the method is based on two complementary logics: an individual logic considering each action separately in a competitive perspective, and a global logic considering groups of actions.

The method combines then these two approaches. The first step is used to select the fundamentals, i.e. actions that appear to obey a pressing necessity either in response to an emergency (a very important risk), or because they are particularly efficient, or because

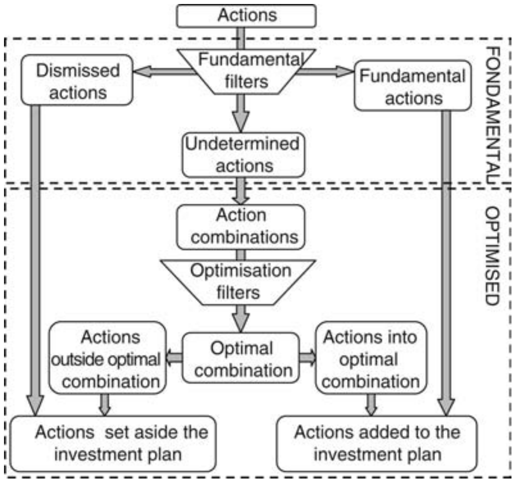

Figure 5. Arbitration approach.

they are integrated into a global strategy. The second step is used to optimize the investment plan, by completing the actions already accepted by actions already selected, based on their relevance within an overall context.

The method will thus consist in submitting actions or action combinations to filters to sort them out into three categories: actions added to the investment plan, dismissed actions and undetermined actions (provisional). The filtering phase stops when the total amount of actions added to the investment plan is equal to the plan budget. As previously mentioned, the method is meant to be interactive and dynamic. Thus, the decision-maker may at any time go back to test new filters, pass from fundamental filters to the optimization filters and go back. The decision-maker is the one to determine his way to the final plan.

3.4.3 *Filters*

Filters lean on sorting functions. These functions are based on variables of departure and on threshold values. A filter can be made up of several sorting functions. The decision-maker can define his own filter in real time, in a totally subjective way; in response to precise needs, integrated into a global strategy, or be chosen for reasons which cannot be transposable in terms of criteria. The strategy to be used to select actions will be based on the choice of filters and their arrangement. This operation will be executed by the decision-maker. The selection filter of an action is called "Dominant Risk". It will allow us to keep traceability with regard to plan justification. Based on the same principles, there are two levels of filters corresponding to each step of the method: fundamental filters for the individual approach and optimization filters for the global approach.

The fundamental filters allow us to form some action groups on the basis of "risk" criteria in selecting actions among the initial set. It should be noted that actions may belong to several groups. The actions which have not been selected remain in the set of undetermined actions. The decision-maker can decide which action groups to select, which to dismiss, or which to be kept in the neutral zone (undetermined actions). We then distinguish between two kinds of fundamental filters. The selection filters place the action in the category of "retained actions". The exclusion filters place the actions in the category of "dismissed actions".

The optimization filters concern the still undetermined actions that were neither retained nor dismissed from the investment plan. They will not be directly allocated to actions, but to combinations of actions.

The first step consists in building these combinations of actions. For this, we consider every action group such as:

- The actions considered belong to the set of undetermined actions
- The combination respects the constraints (budget, delay. . .)
- The combination saturates the constraints

We can then build every possible combination. Then, the aim will be to determine the optimal combination. As for the first step, this phase, driven by the decision-maker, is based on optimization filters. He can apply a predetermined filter, or define his own filter in real time, in a subjective view. At the end of the filtering phase, the decision-maker has to keep only one combination. The actions of the combination will be then added to the investment plan, thus forming the final plan.

3.4.4 *Example*

Fundamental phase

For our experimentation, 10 fundamental filters were used, 7 for selection and 3 for exclusion. Among these filters, two did not retain any action and therefore were not used. A filter was discarded because it did not allow us to respect the budget constraint.

Situation after the fundamental phase:

- 21 retained actions, amount: 1739 k€
- 32 undetermined actions, amount: 2213 k€
- 51 dismissed actions, amount: 7301 k€

Optimization phase

Every possible combination using the 31 remaining actions and saturating the remaining budget (261 k€) was determined. The combination number is 29 604 (calculated by computer). The optimization filters were applied to these combinations.

Table 4. Filters used during fundamental phase.

Type	Nature
Selection	Businesses already started and ongoing for the year considered
Selection	Regulatory urgency
Selection	Urgency on the item situation
Selection	Urgency on the client satisfaction
Selection	Regulatory criticity
Selection	Optimum efficacy
Selection	Optimum yield
Exclusion	Minimum efficacy limited winning on the 3 risks
Exclusion	Too expansive in relation to the remaining budget
Exclusion	Limited yield

The 6 secondary filters used made it possible to choose a solution regarded as optimum by the decision-maker among the 29 604 initial ones.

Type	Nature
Selection	Maximization of the regular conformity
Selection	Maximization of the efficacy
Selection	Maximization of the yield
Selection	Maximization of the min for the 3 domains
Selection	Minimization of the number of critical risks
Selection	Strategic choice

Characteristic of the remaining combination: 8 businesses, amount: 250 k€

Then, we obtained 29 actions added to the plan, for an amount of 1.99 million, respecting the constraint of 2 million euros set by the budget.

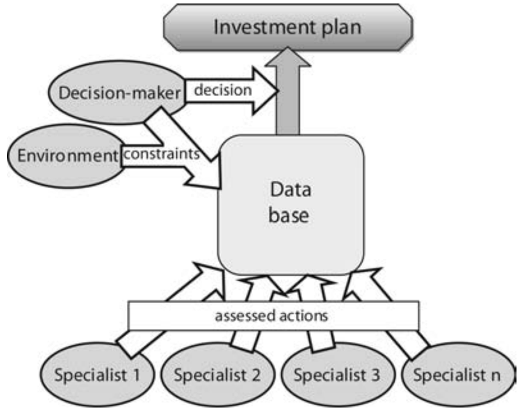

Figure 6. Functional architecture.

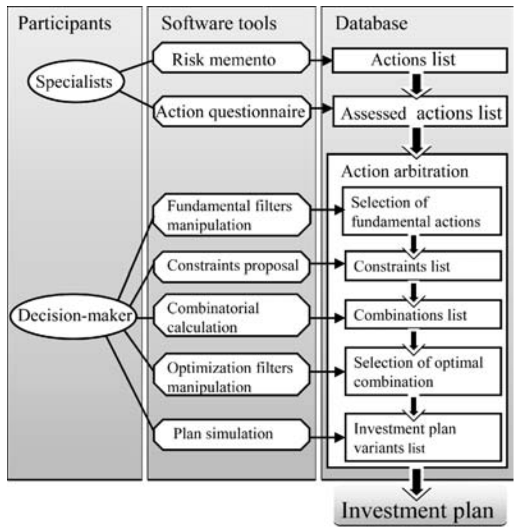

Figure 7. Software composition.

4 SOFTWARE SUPPORT SPECIFICATIONS

4.1 *Concept*

Our method is ergonomic, dynamic, and participatory in the simulation logic. Then, the necessity of the software support becomes obvious. However, the software should not be only a help to the process, it has to be placed at the center to be really efficient. Yet, the key of process is the information. The method lies on a great number of information. The core of the software must be the database. Each participant has to enrich the database, depending of his role.

Then the database must be accessible by every participant (for example by intranet). But the access to the information should depend on the participant role. Specialists should be in charge of information relating to actions identification and assessment in their expertise fields. Decision-maker has to manage information, which would allow constructing the solution. It is also him who defines the constraints from the environment (company strategy, available budget. . .).

The notion of role is primordial in our problem. It allows on a general database, having different visions adapted to the specificity of each participant.

4.2 *Functionalities*

We can dissociate two levels in the software. The first is the database. The second is the tools allowing manipulating the database.

Each of the method phases can be developed on these two levels.

Risk memento
The risk memento is a frame of reference, which gives information on the different kind of risks. It provides a support for the specialist to identify risks and actions but not a total replacement.

Questionnaire action
The questionnaire action allows obtaining the damage potential from a list of questions. Questions focus on the state of the building, regulatory compliance, etc.

Combinatorial calculation
The combination calculation is clearly impossible without the support of computer. The difficulty comes from the combinatorial explosion. We developed an algorithm to solve this problem but we must still limit the number of possibilities.

Filter manipulation
There are two components in this tool. The first offers the possibility to add new filters to the list of already existing ones (predefined filters). The second helps the decision-maker to choose and test filters. To construct properly his solution, he has to test a great number of filters and to multiply its angles of vision (the system is based on the pileup of vision).

Plan simulation
The decision-maker has the possibility of storing various studies and partial results. So he can compare different versions and choose the one which seems the best for him. Note that he can compare the complete plan and the intermediate plan as well.

5 DISCUSSION

5.1 *Evolution of the method*

The application to a real case allows us to validate and to enrich the method. It has undergone different evolutions during the experimentation. The application of the method was preceded by an analysis phase of existing practices. The starting assumption was to stay close enough to these past practices to ensure the proper understanding and good assimilation of the process.

Some items originally planned in the approach have been modified to better reflect the needs and the particular context of the experimental case.

Among these, we can note the following items:

- The probability system initially foreseen by the method was not selected. The technicians qualifying actions had only very few notions of probabilities. The risk was that the probability assessment might be biased, or that some technicians might simply refuse to fill in these fields. That is why we referred to the notion of potential damage.
- Initially, the method used utility functions. Their use was then stopped because of the choice of abandoning the system of probability.
- On the other hand, other points result from the experiments directly:
- The probability was transformed into a system of potential damage. This choice was made in order to ensure the effective assimilation of the process.
- The initial method did not contain specific information on the consequence domains. They were identified during testing from interviews with the various participants (technicians, decision-makers, etc).
- Similarly, the qualification grids were drafted during testing to meet the expectations of the company and the decision-maker. The choice of a rating from 1 to 4 (with a maximum score for the most favorable situation) was made to refer to previously used practices.

5.2 *Positive and negative aspects*

The feedback from our testing was very favorable, in terms of both the approach and the results. The main satisfactions at the level of experimentation are:

- The final plan resulting from the method application seemed to correspond to the expectations of various participants.
- The method has been adopted and can be replicated.
- The arbitration seemed methodical and justified, both for the decision-maker and the technicians.
- New concepts such as efficiency or yield have attracted the decision-maker's attention.
- The complexity of the problem has been properly restored and illustrated: It is very important to note that the decision-maker considers the filters according to their nature rather than their mathematical definition. He actually feels as if he had been working within his usual context.

Nevertheless, some sensitive issues remain. We must analyze them carefully and thoroughly in order to improve the method.

These points are:

- Some of the actions were hard to classify because the three consequence domain did not cover all their special features.
- The qualification grids proposed were not sufficiently accurate and functional to ensure a perfect uniformity of assessments.
- The most important point was the lack of efficient software support. For the moment, there is no adapted software. The computer processing has been unfolded through various software programmes (spreadsheet, database manager, JAVA programme), which are used by default, according

to the method phase. Then, each operation, each construction of plan variant by the decision-maker, took a lot of time and could not be done in real time. During the experiment, we had to limit this kind of operation, thus restricting the angles of vision to the decision-maker, whereas the methodology should precisely offer complete freedom on this point.

5.3 *Points to be dealt with*

This first experiment has helped us to develop and improve our approach, to highlight the main advantages and to reveal certain aspects to be analyzed in detail. We can quote:

- The domain of risk consequences can be extended. During our testing, we used only three domains. At least two aspects have not been considered: the environment (environmental risk impact) and the purely financial aspect (some actions are conducted in the hope of a financial return, such as installing photovoltaic panels).
- The qualification grids have to be specified. It is necessary to detail the qualification grids according to the technical domains in order to facilitate the task of the specialists in terms of scoring their proposed actions.
- The software is in a prototype stage, and we test the fundamental principles in real experiments and complete the specification (as exposed in this article). It would be operational for the next experimentation (end of 2008).

Despite these issues left to be analyzed, experimentation has yet highlighted the relevance of the method and found a very positive response from the company.

6 CONCLUSION

We thus proposed an arbitration method for a building facility management investment plan. The method refers to the classic practices of this sector, enriching them by a risk dimension to better consider the decision complexity. One of its main objectives was to make the combination of actions issued from very different technical domains possible. The Arbitration is methodical, reproducible, and measurable in terms of results. It casts a new light on decision-making. It is transparent by exposing the choice achieved. The logic that combines emergency, optimization and decision allows us to have several angles that show the problem complexity. The method considers not only risks, but it also manages the efficiency of the actions conducted and their cost. That allows us to integrate new notions (efficacy, yield), which are significant to the decision-maker.

The experimentation enriched the method by making it closer to reality. This experimentation has especially showed the relevance of the method. Although the arbitration phase was based on simulation rather than on the fact of implementing a mathematical function, the resulting plan was considered sound and argued and seemed to correspond to the expectations of every participant, ie specialists and decision makers. There are of course points that remain to be refined and completed to make the method more operational, such as the devising of an efficient software tool, but the method has already achieved its objective by providing consistent support to the decision.

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Factors affecting virtual organisation adoption and diffusion in industry

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ABSTRACT: Never in the history of mankind has Information and Communication Technology (ICT) gained such a momentum as that which we witness in our present globalised world. One of the most important features of this state of affairs is e-Business and e-work underpinned by global and localised Virtual Organisations (VO). The paper reveals the complex reality of deployment and adoption of ICT to support e-Business and e-work. It is based on results from the EU funded VOSTER project, which in response to the urgent need to reach the optimal level of VO functioning, sets out to analyze the organizational, economic, legal, and socio-cultural factors affecting technology adoption in the context of a VO. In consideration of the recent literature, the paper identifies current barriers, limitations and insight for the deficient research in VOs, and formulates a number of research challenges for the future.

1 INTRODUCTION

Organizations are currently facing important and unprecedented challenges in an ever dynamic, constantly changing, and complex environment. Several factors, including the pace of technological innovation and the globalization of the economy, have forced business and industry to adapt to new challenges triggered by an ever sophisticated society characterized by an increasing demand for customized and high quality services and products in various segments of industry. Virtual organizations are believed to have high potential. The power of technology in supporting e-Business and e-work by global and localised VOs continues to improve (Davis 1989). While a number of technical requirements emerge to support e-business and e-work, the migration of traditional organizations to empowered VOs is hindered by a number of barriers. These include the broader factors related to culture, organizational structure, decision making processes, perceptions in relation to change, shared responsibility management, liability, copyright and confidentiality issues, trust, employee-manager relationships, management strategies, and ICT maturity and capability (Carmarinha-Matos & Afsarmanesh 2005, Rezgui & Wilson 2005). As technical barriers disappear, the challenge becomes in understanding employees' acceptance and resistance patterns of technology (Venkatesh et al 2003).

Although the potential advantages of the VO are well known at the conceptual level, their practical implantation is still far below their potential. The barriers related to VOs' employees acceptance and adoption of technology to support their formation and operations has been little researched.

During the last years, the European Union has been particularly active in this area. Numerous projects and studies have been carried out with the aim of establishing technological foundations for the support of VOs. In general, however, looking at the top-notch research, the findings fill short of discussing acceptance of technology models. In order to leverage the potential benefits of the agile VO paradigm, given the complexity of this phenomenon as well as the lack of research to date, there is an urgent need to raise acceptance of cooperative technology models as a critical research agenda topic. This in turn pours into the industrial and academic need to define a common reference model to support the life cycle of the VO.

In consideration of the recent literature, eight technology acceptance models provide a frame of reference for the adoption of VOs. These are the theory of reasoned action (Fishbein & Ajzen 1975), the technology acceptance model (Davis 1989), the motivational model (Davis et al 1992), the theory of planned behavior (Ajzen 1991), a model combining the technology acceptance model and the theory of planned behavior (Taylor & Todd 1995), the model of PC utilization (Thompson et al 1991), the innovation diffusion theory (Moore & Benbasat 1991), and the social cognitive theory (Compeau & Higgins 1995).

This paper summarizes the technologies and standards that serve as enablers for the development of the required support infrastructures for VOs. It reveals the

Table 1. Existing and emerging technologies and standards.

Technologies and standards	Purpose	Examples
Resource management technologies	Address sharing of resources in the VO, where the resources can be information, hardware or software	Globus Toolkit, DAIS, Spitfire, GridFTP, Replica Manager
Distributed information management	Provide generic mechanisms for sharing and exchange of information among	DiscoveryLink, Virtuoso, PEER, Donaji
Workflow management systems	Address the organization of activities required to accomplish a task, and specify rules for the correct execution and successful completion of the activities	MetuFlow, WebWork, WfM, BPEL4WS, WS-Coordination/Transaction
Inter-operability middleware	Addresses the system heterogeneity. In order to share resources among multiple organizations and organize tasks whose execution may span multiple organizations.	COBRA, Web services, UDDI,Semantic Web, Globus Tollkit
Development technologies	Providing the software environment suitable for large distributed system development	NET, J2EE
Information modeling standards	Address the representational aspects of information. Standardization for interoperability.	ODMG, WebDAV, Dublin Core
Information exchange	Focus on the syntactic aspects of information	XML, EDI, WSDL, WSIL
Communication protocols	Addressing distributed object access protocol	SOAP
Security standards and protocols	Focusing on different aspects of security in distributed networks	PKI, XACML, SAML, XKMS, XMLDSIG, XMLENC, WS-Security
Technologies related to B2B	Focused on framework definitions and tools for B2B collaboration	RosettaNet, ebXML, OAGIS, FIPA

complex reality of deployment and adoption of VO practices and identifies a number of organizational, legal, economic, and socio-cultural challenges that VOs face in adopting ICTs to support e-Business and e-work. It presents key results from the EU funded IST VOSTER project in which the authors were involved. In response to the urgent need to reach the optimal level of VO functioning, the present research set out to analyze the organizational, economic, legal, socio-cultural issues in light of the technology acceptance models to better understand the factors affecting technology adoption in the context of VOs. In consideration of the recent literature, the paper identifies current barriers, limitations and insight for the deficient research in VOs. It identifies a gap in formal theories, structure, modeling, and life cycle behavior of VOs where a proposition for the future direction is drawn.

2 ICT INFRASTRUCTURES FOR VO

As virtual organizations rely on technologies to support their e-Business and e-work, Table 1 categorizes existing and emerging technologies and standards that may serve as enablers for the development of the required support infrastructures for VOs (Camarinha-Matos & Afsarmanesh 2005), where each category in turn contains a number of examples in order to study related technologies and standards.

3 ACCEPTANCE OF TECHNOLOGY

While it has been argued that innovative technologies and architectures support e-Business and e-work in VOs, and are being widely adopted in the workplace, little is known about their acceptance. In consideration of the current literature, information technology acceptance research has yielded many competing models, each with different sets of acceptance determinants.

3.1 *Theory of Reasoned Action (TRA)*

Drawn from social psychology, the components of TRA are two constructs *attitude towards behavior*, and *subjective norm*. *Attitude Toward Behavior* defined as “an individual’s positive or negative feelings (evaluative affect) about performing the target behavior” (Fishbein & Ajzen 1975). *Subjective Norm* seen as “the person’s perception that most people who are important to him think he should or should not perform the behavior in question” (Fishbein & Ajzen 1975).

3.2 *Technology Acceptance Model (TAM)*

It posits that two particular beliefs, perceived usefulness defined as “the degree to which a person believes that using a particular system would enhance his or her job performance” (Davis 1989) and *perceived ease* *of' use* referring to "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989) are of primary relevance for computer acceptance behaviors. TAM2 extended TAM by including subjective norm, adapted from TRA/TPB, as an additional predictor of intention in the case of mandatory settings (Davis 1989).

3.3 *Motivational Model (MM)*

Grounded in psychology research, motivation theory explain behavior based on two constructs*: Extrinsic Motivation* defined as the perception that users will want to perform an activity "because it is perceived to be instrumental in achieving valued outcomes that are distinct from the activity itself, such as improved job performance, pay, or promotions" (Davis et al 1992). Intrinsic Motivation seen as the perception that users will want to perform an activity "for no apparent reinforcement other than the process of performing the activity per se" (Davis et al 1992).

3.4 *Theory of Planned Behavior (TPB)*

In TPB, perceived behavioral control is theorized to be an additional determinant of intention and behavior along with Attitude Toward Behavior and Subjective Norm adapted from TRA to predict intention and behavior in a wide variety of settings. A related model is the Decomposed Theory of Planned Behavior (DTPB). DTPB decomposes Attitude Toward Behavior adapted from TRA, subjective norm adapted from TRA, and perceived behavioral control defines as "the perceived ease or difficulty of performing the behavior" (Ajzen 1991) into the underlying belief structure within technology adoption contexts.

3.5 *Combined TAM and TPB (C-TAM-TPB)*

This model combines Attitude Toward Behavior, Subjective Norm, Perceived Behavioral Control predictors of TPB with Perceived Usefulness from TAM (Taylor & Todd 1995).

3.6 *Model of PC Utilization (MPCU)*

In keeping with the theory's roots, MPCU posits that Job-fit is defined as "the extent to which an individual believes that using a technology can enhance the performance of his or her job" (Thompson et al 1991). Complexity defined as "the degree to which an innovation is perceived as relatively difficult to understand and use" (Thompson et al 1991). Long-term Consequences refers to "Outcomes that have a pay-off in the future" (Thompson et al 1991). Affect Toward Use is "feelings of joy, elation, or pleasure, or depression, disgust, displeasure, or hate associated by an individual with a particular act" (Thompson et al 1991). Social Factors are "the individual's internalization of the reference group's subjective culture, and specific interpersonal agreements that the individual has made with others, in specific social situations" (Thompson et al 1991). Facilitating Conditions refers to the provision of objective factors in the environment that observers agree make an act easy to accomplish (Thompson et al 1991).

3.7 *Innovation Diffusion Theory (IDT)*

Grounded in sociology, the model suggests that the speed of new ideas and technology adoption is determined by seven innovation characteristics, these are: Relative Advantage defined as "the degree to which an innovation is perceived as being better than its precursor" (Moore & Benbasat 1991). Ease of Use defined as "the degree to which an innovation is perceived as being difficult to use" (Moore & Benbasat 1991). Image defined as "the degree to which use of an innovation is perceived to enhance one's image or status in one's social system" (Moore & Benbasat 1991). Visibility defined as "The degree to which one can see others using the system in the organization" (Moore & Benbasat 1991). Compatibility defined as "the degree to which an innovation is perceived as being consistent with the existing values, needs, and past experiences of potential adopters" (Moore & Benbasat 1991). Results Demonstrability defined as "the tangibility of the results of using the innovation, including their observability and communicability" (Moore & Benbasat 1991). Voluntariness of Use defined as "the degree to which use of the innovation is perceived as being voluntary, or of free will" (Moore & Benbasat 1991).

3.8 *Social Cognitive Theory (SCT)*

The model suggests four constructs, these are: Outcome Expectations—Performance_refers to the performance-related consequences of the behavior (Compeau & Higgins 1995). Outcome Expectations—Personal refers to the personal consequences of the behavior (Compeau & Higgins 1995). Self-efficacy refers to judgment of one's ability to use a technology to accomplish a particular job or task. Affect refers to an individual's liking for a particular behavior. Anxiety refers to evoking anxious or emotional reactions when it comes to performing a behavior.

As a matter of fact, when practitioners are presented with a new ICT infrastructure, eight models may serve as determinants of individual intention and acceptance of technology usage.

4 METHODOLOGY

In attempt to contribute to the individual acceptance of the existing and the rapid evolution of innovative ICT infrastructures and architectures required to support e-Business and e-work in VOs, the paper draws on the literature and reports results from the IST VOSTER project to analyze the data acquired in the twenty three relevant EU funded research projects in light of the eight acceptance of technology models. The basic idea was, to capture the most relevant aspects of virtual organizations and to understand their underlying technological, business and management set-up and principles. This involved the analysis of the twenty-three EU research projects (illustrated in Table 2) conducted according to a number of dimensions. These dimensions are presented below:

1. Business rationale for the virtual organization: The reasons why virtual organization was chosen by the partners involved as opposed to other forms.
2. Structure of the Virtual Organization
   - Operational VO Structure: Topology used for operating the virtual organization
   - VO Governance Structure: Topology used for governing (decision making, negotiating rules) the VO (if different from operational structure)
   - Source Network for the VOs: Underlying organization for forming VOs assumed by the project; topology and boundary criteria of the structure?
3. Business Processes
   - Processes for source network: Models for processes (esp. management processes) for creating, developing and administering the underlying source network for VOs
   - VO Management Processes: Models for management processes defined for creating, developing, controlling, and dissolving the VO
   - VO Operational Processes: Models for the operational processes within the VO (e.g. product development, production planning and scheduling)
   - VO Support Processes: Models for support processes within the VO (e.g. administration, finances, human resources). All process models should include the related information view and other views
4. Change in the VO and its source network
   - Change Patterns: The typical forms of change for the VO and for the source network, such as lifecycle, evolution, design or negotiation
   - Preparedness for change: The capabilities, investments and attitudes towards handling of change assumed for the source network, the VO and the individual company (relating to participating in VOs)?
5. Business Model
   - Risk and Reward Sharing: Models for distributing risk and rewards within the VO and source network
   - Liability and Aftersales Responsibility (Guarantee): Models for organizing guarantee and aftersales for the VOs and source networks
6. Management Roles for the VO and source network: Roles consisting of a set of tasks, competencies, and power related to the creation, operation and survival/development of the VO and its source structure. The role can be taken by a single person or an organizational entity (partner, department, etc.) and be positioned at source structure, VO or individual enterprise level.

5 DISCUSSION

Having set the stage for the analysis, this section discusses the VOSTER results using the constructs from the different models that play a significant role as direct determinants of user acceptance and usage behavior.

VOs' investment in innovative technologies and architectures to support e-Business and e-work is inherently at risk if individual acceptance of technology is overlooked and usage behavior not given enough importance. In parallel with technological developments, it is mandatory to reach some level of individual and group acceptance of technology. The objective here is to provide organizations with the pivotal ability to harness the power of ICT applications by considering determinants of individual acceptance of technology and usage behavior which pours into the e-Business and e-work pool.

It is fair to say that, the Perceived Usefulness, Extrinsic Motivation, Job fit, Relative Advantage, and Outcome Expectation constructs from the different models that pertain to the individual's belief that using the ICT will help them attain gains in job performance, to some extent, accounts for the effective enforcement of ICT to support e-Business and e-work. This implies how the employee perceives the capabilities of a technology to be instrumental in achieving valued outcomes that are distinct from the activity itself, i.e. improved job performance (Davis et al 1992).

To give an example, in the construction industry projects which are performed on a team basis by nature, a very important fact should be highlighted to verify the authenticity of the constructs and understand the determinants of technology acceptance. Construction small enterprises in Europe are known for being very fragmented, less innovative than in other sectors, and based on traditional business models. The rapid pace of ICT provides the opportunity to relax traditional business modes of operation (Powel et al 2004). To this end, virtual working can be seen as a more systemic way to build cooperation (Rezgui & Wilson 2005, Rezgui 2007)

OSMOS scope is based on the need to specify internet-based services to support collaboration and co-ordination of interaction between individuals and teams on projects; while, e-COGNOS expounded business recommendations in order to improve decision-making and business processes throughout the design

Table 2. Voster projects.

Project Acronym	Short Description
eMMEDIATE	The project redesigns existing business structures and procedures towards the shape of "smart organization".
PRODCHAIN	The project develops a decision support technique to analyze and improve the performance of globally acting production and logistics networks.
PRODNET II	The project designs and develops an open platform and the adequate IT protocols and mechanisms to support Virtual Industrial Enterprises.
eCOGNOS	The project addresses electronic consistent knowledge management across projects and between enterprises in the construction domain.
ELEGAL	Defines a framework for legal conditions and contracts regarding the use of ICT.
GLOBEMEN	The project defines the architecture for globally distributed product life cycle phases.
ICCI	Enhances the co-ordination of research and developments in Construction IT.
ICSS-BMBF	The aim of the Integrated Client Server System approach is the development of an integrated client-server system encompassing all team members in an entire building construction project.
ISTforCE	The approach provides a personalized human-centered environment, enhancing current, less flexible project-centered approaches.
OSMOS	The approach specifies a model-based environment where the release of, and access to, any shared information produced by actors participating in projects is secure, tracked, and managed transparently.
ProDAEC	The project sets up and sustains a Thematic Network for the European AEC sector that promotes the use and implementation of standards and best practices regarding product data exchange, e-work and e-business.
BAP	The project facilitates the optimal design, efficient and effective operation and ultimate success of virtual enterprises.
BIDSAVER	The project defines a framework for the constitution and operation of VOs.
E-COLLEG	The project defines transparent infrastructure that will enable distributed engineering teams to collaborate during the design of complex heterogeneous systems.
EXTERNAL	The project provides solutions that make forming an extended enterprise (EE), characterised by a dynamic and time-limited collaboration between business partners effective and repeatable.
FETISH-ETF	The project explores methodologies to allow tourism organizations and enterprises to register their services in federations of services under a VE perspective.
GENESIS	The project involves the adaptation and fine-tuning of the already available methods of the Value System Designer, towards the new class of users' needs.
GNOSIS	The objectives are about the development of the Virtual Factory Platform.
MASSYVE	The project develops an advanced layer on top of agile scheduling system prototype, previously developed, extending the system towards a virtual enterprise.
SYMPHONY	The project explores dynamic management methodology with modular and integrated methods and tools to support major management concerns.
UEML	The project facilitates interoperability in the frame of on-going standardization; define a core set of modeling constructs; demonstrate the concepts; prepare a project to define, implement, extend, the complete UEML.
VDA	The project provides an extensive range of services and a dissemination platform in order to establish a one- stop- shop for the tourist customer.
VL	The project explores necessary technical and scientific computing framework to fulfill requirements of several scientific and engineering application domains.

and construction stages. Both projects are significant in the context. The focus of OSMOS and e-COGNOS was to offer solutions for collaboration between all the actors in a construction project and between enterprises in the construction domain.

The general extent to which the use of the ICT could assist in the job plays a significant role as direct determinants of user acceptance and usage behavior. In the construction industry, from a practical point of view, most of the project organizations are VOs.

Employees in this field may have different roles in different projects, working in a fast changing field that requires continuous adaptation to new situations that support cooperation and allow coordination of interactions between individuals and teams in a construction VO. Therefore the Perceived Usefulness, Extrinsic Motivation, Job fit, Relative Advantage, and Outcome Expectation are key concepts for these VOs.

The models coupled with the construction practice underline the significance of the individuals' believes that using the system will help him or her to attain gains in job performance despite using different labels. So, e-Business and e-work gives rise to the fundamental requirements of labor division into tasks and the coordination of these tasks (Kürümlüoglu et al 2005, Rezgui & Wilson 2005, Rezgui 2007, Vakola & Wilson 2004).

The digital communication revolution has enabled partners within the virtual organization to increasingly use collaborative environments as a means of managing their communication (Shelbourn 2005). These organizations are legally independent. A group of researchers in the eLEGAL project implemented legal support tools and promoted an enhanced business practice in which the use of ICT in information exchange is contractually stipulated to support collaboration. eLEGAL develops software tools for contract editing and configuration together with a virtual negotiation room to coordinate collaboration. To this end, attention should be paid to acceptance of technology laying emphasis on Perceived Usefulness, Complexity, and Ease of Use. These constructs from the different models contain the explicitly or implicitly notion that the organization support for the use of the ICT system is significant in the context to improve virtual collaboration performance and co-ordination of interaction.

Each of Perceived Behavioural Control, Facilitating Conditions, and Compatibility constructs include aspects of technological or organizational environment that are designed to remove barriers to ICT use. It is fair to say that the availability of guidance in the selection of the system, the availability of specialized instruction concerning the system, and the availability of specific assistance with system difficulties are significant facilitating conditions related to the support infrastructure which partially account to tap the fit between the degree to which a VO innovation is perceived as being consistent with existing values, needs and experiences of potential adopters.

A very important fact should be highlighted in order to understand the creation and operation of VOs. The ICCI, ISTforCE, BAP, BIDSAVER, E-COLLEGE, EXTERNAL projects discussed the cooperation of production ingredients. Achieving competitiveness and maintaining good cooperation cannot depend solely on mutual faith.

The fact of the matter is that the creation and operation of the organization alliance is regarded as a change initiative within the participating organizations. Let aside the fact that is established from the analysis of findings from the VOSTER projects that virtual organization members are likely to experience lifecycle problems– set up, operation, and winding down, where each of these different phases is likely to involve change in staffing, tasks, objectives and resources (Rezgui 2007), but the question that emerges from unanimous projects and remains unclear is: what enables perception, awareness, and preparedness to change?

While most research (Pawar & Sharifi 2000, Barrett & Sexton 2006) and proposed PRODCHAIN, e-COGNOS, ProDAEC approaches in this area have been unable to break away from the traditional models, it is worth mentioning the role of Subjective Norm, Social Factor, and Image constructs from the different models in virtual organization settings. While they have different labels, in VO settings these posit that employee's behavior is influenced by the way in which they believe others will view them as a result of having used the technology. In fact, the role of Subjective Norm, Social Factor, and Image constructs in technology acceptance from this perspective implies that employee's behavior is partially guided by the perception that the manager believes he or she should or should not perform the behavior in question**.** To cope with the complexity resulting from non-collocation associated with e-Business and e-work, it is essential that team managers play a pivotal role to relate and identify members to themselves (the manager).

Generally speaking, the use of e-Business and e-work has exposed concerns of trust associated with electronic collaboration within virtual organizations. The core of OSMOS and SYMPHONY projects results on trust centers on a belief that only trust can prevent the geographical boundaries and time zones of virtual organizations' members from becoming psychological distances. SYMPHONY and OSMOS results suggest that face-to-face interaction at the inception stage where the vision, mission, and goals can be communicated and shared has a direct impact on organization performance through building team trust and enabling team members to exchange valuable socio-cultural information. Extending this idea even further, the OSMOS project recommends including face-to-face interactions when possible during the virtual organisation lifecycle to provide the grounds for a worthwhile ICT collaboration. At this (the ICT collaboration) time, lies the role of Attitude Towards Behaviour, Intrinsic Motivation, Affect Towards Use, and Affect. These constructs assume that the individuals' collaboration performing is controlled by an individual's beliefs about the presence of factors that may facilitate or impede performance of the behavior. It is sufficient to say that factors, which foster a culture of extensive collaboration, are requirements the team needs in order to benefit from the diversity and dispersion in the virtual organization environment which were lacking from the IST VOSTER analysis and the current literature.

6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The aim of this paper is merely to shed light on the organizational, economic, legal, and socio-cultural factors affecting technology adoption in the context of a VO.

However, it is hoped that the paper succeeds in sighting for the deficient research in VOs which hinder full exploitation of this environment. This is expressed in the form of open research questions for the VO community.

The fact of the matter is that the power of ICT in supporting e-Business and e-work continues to improve, but the questions are: whether virtual teams can function effectively in the absence of frequent face-to-face communication? Further research should address which, if any, team training accustoms expert team members in their fields to the particular requirements of virtual working? How would members relate and identify themselves to their manager in a virtual context? In the worst case scenario, what requirements the team needs to benefit from the diversity and dispersion regardless of trust?

How team members in a virtual context build, sustain and strengthen culture in the absence of frequent face-to-face interaction? How often should the team members communicate to remain glued? What current organizational culture circumstances hinder team effectiveness in the virtual environment? Can a set of cultural attributes that promote effectiveness of teams be identified? How can these attributes be effectively enforced in virtual organisations to ensure that members remain glued?

How to manage intellectual property rights and cope with copyright and confidentiality issues? How to manage responsibility? How to share and distribute liability? How to monitor these throughout collaboration? How shared responsibility by means of rights and ownership of outcomes is identified? How these foundations can be blended together to generate the basic building block to deliver sound legal entity?

How to share profits and losses in the context of an organization alliance? How to ensure that the collective financial gain of the organization alliance outweighs the individual profits of associated member organizations? How organizations evaluate and determine the right economic costing in a consistent manner across the network?

What structural work arrangements are best suited to the work that must transcend geographical boundaries and time? How organizations effectively enforce these structures? What are the necessary abilities of the manager to facilitate communication among team members to create clear structures and foster role clarity to improve collaboration? What tasks enable perception, awareness, and preparedness to change? Do traditional managerial change mechanisms remain applicable in the virtual organization alliance environment? Either wise, what are the most appropriate change mechanisms? What business and organizational methods offer innovative and sustainable services along the collaboration? What formulas, depending on the nature and scale of the organization changes, are effective for decision-making? What is the necessary vision and systemic thinking required to manage the change lifecycle?

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Current & future RTD trends in modelling and ICT in Ireland

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Towards a framework for capturing and sharing construction project knowledge

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ABSTRACT: As construction projects are executed, new problems are encountered and solutions arrived at which are rarely documented, the lessons learned residing only with the individuals directly involved in the project. This knowledge is highly valuable to the wider construction organization and has the potential to reduce the reoccurrence of such problems and reinventing of the wheel. Based on case studies of two of the leading Irish construction organizations, this paper presents the development of a framework for capturing and sharing construction project knowledge. The first case study evaluated existing lessons learned practices, while the second adopted an action research approach to capturing and sharing construction project knowledge. Central to this framework is the adoption of lessons learned practices which are closely aligned to the organization's Continuing Professional Development activities. By providing learning opportunities for individual employees, the collective capturing and sharing of construction project knowledge can be improved for the benefit of the organization.

1 INTRODUCTION

The need for construction organizations to manage their knowledge in a more formal manner for improved performance is well recognized. There has been much research into knowledge management (KM) for the construction industry in recent years, yet still it remains a recent and evolving practice for construction organizations. The project-based, temporal nature of the industry has hindered the development of effective KM solutions for large, geographically dispersed construction organizations. There is no single solution for KM, rather it is concerned with the creation and subsequent management of an environment which encourages knowledge to be created, shared, learnt, enhanced, organized and utilized. Two of the main disciplines to have embraced the KM discourse are information systems and human resource management, an integration of these having the greatest potential for advances in the field. The lack of a working definition of knowledge within construction organizations and awareness of the importance and potential advantages of KM reflects a casual approach, and indicates the need for further exploration of knowledge and KM-related issues (Robinson et al. 2005). There is a dearth of empirical research and integrated KM models for construction, resulting in the continuing need for the development and testing of such models (Walker & Wilson 2004). In terms of capturing and sharing construction project knowledge, lessons learned (LL) practices are one of the key elements of KM initiatives for construction organizations. The purpose of LL is to capture experiences, successful or otherwise, allowing an organization to avoid repeating costly mistakes, improve future performance and ultimately, the contractor's profit (Carrillo 2005). In a study of American contractors, Fisher et al. (1998) identified a number of other reasons for implementing a formal LL process as: high staff turnover leading to loss of experience; large size of organizations make sharing knowledge difficult; and departmental silos and fragmentation within the organization. Based on an ongoing doctoral study, the aim of this paper is to propose a framework for the capturing and sharing of construction project knowledge. Following a review of literature, the research methodology for the two case studies is considered with the findings presented and discussed. The paper concludes by proposing an emerging framework for lessons learned within construction organizations.

2 LESSONS LEARNED PRACTICES

Lessons learned (LL) practices are an important aspect of KM. LL practices refer to "the activities, people and products that support the recording, collection and dissemination of lessons learned in organizations (Snider et al. 2002)." Two key issues were identified by Kartam (1996) in the development of LL practices, a manageable format for organizing, storing, retrieving and updating information and an effective mechanism for collecting, verifying, categorizing and storing information. In devising such practices, Robinson et al (2005) identify two distinct strategies; codification and personalization. Codification involves capturing knowledge in an explicit form and leveraging it using IT tools such as a LL database (LLDB). Personalization focuses on sharing tacit knowledge through human interaction. While a combination of both codification and personalization is most appropriate (Kamara et al. 2002, Fisher et al. 1998 and Voit & Drury 2006), there has been a scarcity of solutions about how to effectively marry social processes with technology (Dixon 2004).

2.1 *The lessons learned process*

Fisher et al. (1998) developed a process for lessons learned, comprising three stages; collection, analysis and dissemination.

2.1.1 *Collection*

The identification and capture of a LL is an extremely difficult process, with a variety of tools identified such as post project reviews and debriefing (Disterer 2002 & Kartam 1996). Two approaches have been identified for collection of LL; "a 'sought input' type collection process, where a custodian of the LL obtains input from various agencies (Fisher et al. 1998)" and a requirement for individuals to submit LL themselves (Kartam 1996).

2.1.2 *Analysis*

A LL must be significant in that it will have a real impact, valid in that it is factually and technically correct and applicable in that it identifies something that eliminates the potential for future failures or reinforces a positive result (Weber and Aha 2002). The analysis of contributed LL is vital considering that "construction practitioners will not accept an assertion that a certain method is superior to another, without a sound rationale (Kartam 1996)." Fisher et al. (1998) recommend that analysis of LL be carried out by a team of senior staff with extensive industry experience. In documenting a LL, Kartam (1996) identifies three key components required, a title describing the lesson, information regarding the source and context from which the lessons is collected, and a means for sufficiently classifying the lesson in a manner that allows fast, clear retrieval by multiple parameters.

2.1.3 *Dissemination*

This can occur by two methods, push and pull. Push methods deliver the LL directly to the user based on their role, interests, training and experience, while pull methods leave the burden of search to the user, who must devote their attention to the source (Weber & Aha 2002). In this context, Weber and Aha (2002) discuss the distribution gap which refers to "the difficulty of transmitting lessons between a lessons learned repository and its prospective user." This can occur for a number of reasons: distribution is not part of organizational processes, users may not know or be reminded of the repository, users may not have the time or skill to retrieve and interpret textual lessons, and subsequently apply the lessons successfully (Weber & Aha 2002). A study by Fong and Yip (2006) identified e-mail or written documents as the most suitable distribution channels for lessons to construction professionals, intranets or websites being the least suitable.

2.2 *Implementing lessons learned practices*

In attempting to implement LL practices and indeed other KM initiatives, a number of challenges have been identified (see Table 1 for LL specific challenges), including poor organizational culture, lack of top management support, lack of dedicated resources such as staff, time and money, and poor ICT infrastructure (Fisher et al. 1998, Snider et al. 2002, Kartam 1996, Carrillo 2005 & Weber and Aha 2002).

To improve LL practices, Davidson (2006) advises that the lessons should be regularly reviewed to ensure accuracy, reliability and relevance, incorporate appropriate LL into business processes, training and checklists, educating people to use the LLDB, demonstrate the value in sharing LL and provide positive feedback to contributors and users. Voit and Drury (2006) identify two key aspects of LL programs as influencing program effectiveness; information usefulness and human intermediary activities. Information usefulness

Table 1. Challenges in adopting LL practices in construction.

Lack of time to capture and use learning experiences
Captured at end of project when many people have moved on
Lost insight due to time lapse between lesson and recording
Failure to uniformly document LL in a useful manner
Lack of proper classification system
Integrating with existing operations and procedures
Sharing lessons between experienced and inexperienced staff
No motivation or perceived benefits for individual employees
Failure to deliver lessons when and where they are needed
Requires people to internalize LL and apply them at work
Difficult to measure and communicate benefits

is the perceived usefulness of the lesson learned, particularly in relation to an individual's current job responsibilities. To reinforce the importance of the LL program, human intermediaries (e.g. managers) should monitor and review their staff's use of the LL. In order to create an environment conducive to learning, senior management need to visibly support an LL initiative, assess the organisation's culture, eliminate barriers, set goals, get departmental buy-in, designate a champion, empower workers, allocate resources, and measure and track results (Robinson et al. 2005 & Fisher et al. 1998).

3 CONTINUING PROFESSIONAL DEVELOPMENT

The development of technical knowledge in the specialist subject area; personal transferable skills and attributes such as team working and problem solving; and general managerial skills are identified as the main areas of learning for professionals (Roscoe 2002). In order to develop these skills, CPD is important and is defined as: "the planned acquisition of knowledge, experience and skills and the development of personal qualities necessary for the execution of professional and technical duties throughout a construction professional's life (Wall and Ahmed 2005)." Three of the main stakeholders in CPD are the individual member, the professional body to which they belong and employers of professional staff who are concerned with maintaining the competence of their staff (Roscoe 2002). It is important that employers afford their employees the opportunity to reflect on their practice, learn from mistakes and seek guidance in a supportive organizational environment (McDougall and Beattie 1998). While much informal learning occurs through on-the-job experience, there are a number of activities which can account for formal CPD, such as completion of training courses and post-graduate academic studies. Other activities which can contribute to formal CPD and are recognized by professional bodies include conferences and lectures, private study and reading, tutoring and mentoring, tours and site visits, open distance learning, workshops and seminars, teaching and examining, working groups, and research publications (CIOB 2007, Engineers Ireland 2007, SCS 1996 & ICPD 2006). Participation in such activities can allow employees the opportunity to "reflect upon their work, trade stories and ideas with co-workers, or catch up on professional theory and practice (Grisham & Walker 2005)." Roscoe (2002) contends that individuals undertake CPD, not only to satisfy their professional body's requirements, but to ensure credibility with colleagues and employers, improve current job performance, widen and deepen the capacity to perform in the current role and develop future capacity to enable promotion and progression.

3.1 *Linking lessons learned to CPD*

A central problem of promoting learning across an organization is that despite people acting collectively, they actually learn individually (Kleiner & Roth 1997). Terrell (2000) contends that far from being learned, lessons are at best, observed, particularly in project-based organizations who have found it extremely difficult to capture and reuse the LL (Dixon 2004). In order to move beyond this, Dixon (2004) believes that LL need to be connected to social processes, "the development of relationships, reflective conversations, probing questions and in-depth interactions – that are the backbone of knowledge sharing." In an attempt to address this issue, Turner Construction has devised a knowledge network to develop and train individual employees, aligning learning with the overall business strategy, improving both individual and organizational performance. Adopting a blended learning approach, Turner utilizes its own experiences and knowledge to develop both face-to-face and web-based CPD courses for its staff (Lemons 2005). Training is viewed as an important part of LL practices, in promoting the use and benefits of LL practices and incorporating actual LL into training (Fisher et al. 1998, Fong and Yip 2006).

3.2 *Engineers Ireland*

Engineers Ireland, the largest professional body in Ireland, has introduced a CPD accreditation scheme for member organisations in a range of engineering-related sectors. The scheme is designed to support lifelong learning by stimulating and recognising good organisational practice in the areas of professional development for engineers and technical staff (but can also be applied to all staff members in all areas of an organisation). Organisations are required to meet the following criteria: a CPD policy, individual training needs analysis and performance management, an average of 5 days formal CPD per annum, a mentoring programme, involvement with professional institutions, and a KM system. Suggestions offered for knowledge sharing and KM include: regular briefings by staff to share technical and business knowledge, a company library, a lessons learned database, an engineering forum and an annual company symposium.

4 RESEARCH METHODOLOGY

The research reported upon within this paper forms part of a wider doctoral study, the aim of which is to develop a model of KM for the leading Irish construction organizations. Education and guidance resources will be developed for these organisations, based upon the developed model. Grounded theory is the over-riding research methodology for the collection and analysis of data and development of the KM model. This approach adopts an emergent design, and through a rigorous analytical process produces explanations that are recognisable to the subjects of the research (Denscombe 2003). Adopting theoretical sampling, a considerable amount of empirical research has been conducted to-date. This includes a survey of Managing Directors and IT Managers in the leading twenty Irish construction organisations, in-depth interviews with senior managers from ten of these, and two in-depth case study organisations. The two case studies focussed on KM practices within the organisations and form the basis for the emerging framework for capturing and sharing construction project knowledge. Both were selected on the basis of their involvement in the Engineers Ireland CPD accreditation scheme. In total, fifteen of the top twenty Irish construction organisations are engaged in the CPD accreditation scheme, highlighting the importance of KM and the need for this research.

A case study approach was chosen as it seeks a range of different kinds of evidence in a case setting, which when abstracted and collated has the potential to provide the best possible range of answers (Gillham 2000 & Robson 1993). A multi-method approach to data collection was employed comprising semi-structured interviews, focus groups and self-administered questionnaires, which were conducted with a variety of individuals within both case study organizations (Robson 1993).

4.1 *Case study 1*

Following an interview with a director from an earlier phase of research, the possibility of conducting some in-depth research within his organization emerged. Case Study 1 directly employ in excess of 700 staff, undertaking a range of large construction projects throughout Ireland from offices located in Dublin, Cork, Limerick and Galway. In 2004, they became the first construction company in Ireland to be awarded accreditation for their CPD practices by Engineers Ireland. During the course of the director interview, a number of topics related to managing knowledge were highlighted by the director including a lessons learned database (LLDB) and knowledge-sharing seminars.

4.1.1 *Staff questionnaire*

Due to a number of constraining factors including the geographical dispersion of staff at various construction site locations, a self-administered questionnaire was deemed the most appropriate data collection method. The purpose of the questionnaire was to explore the effectiveness of identified KM initiatives within the organization, such as the LLDB, knowledge-sharing seminars and CPD. The selection of a suitable sample was based on discussions with the director and the company's human resource (HR) manager with a view to maximizing the response rate. Subsequently the questionnaire was e-mailed to 180 professional and management staff, achieving a 36% response rate.

4.1.2 *Project team interviews*

With the questionnaire completed, it was decided to undertake in-depth semi-structured interviews with a full project team based on a €70 million commercial development project in the south-east of Ireland. The interviews allowed for expansion upon issues covered in the questionnaire. The interviewees comprised thirteen professional and management staff, including a senior contracts manager, a project manager, three quantity surveyors, three engineers, four foremen and a safety officer.

4.2 *Case study 2*

The second case study focused upon capturing and sharing cleanroom construction knowledge within the pharmaceutical division of another leading Irish construction organization. Employing in excess of 1000 staff in Ireland, Case Study 2 executes projects in a variety of sectors including civil engineering, residential, industrial and commercial. Action research was adopted as the overall research strategy, which is based on a collaborative approach between the researcher and the practitioner with the aim of solving a problem and generating new knowledge. According to Denscombe (2003) it is normally associated with 'hands-on', small-scale research projects where practitioners wish to use research to improve their practices. Two phases of research were completed with a view to developing a framework for capturing and sharing specialist construction project knowledge within the pharmaceutical division. This is particularly important as Case Study 2 frequently complete cleanroom projects through the management contracting route, which requires the organization to demonstrate their knowledge and experience to prospective clients.

4.2.1 *Phase 1*

The earlier stages of the doctoral study identified the important role of middle managers in sharing knowledge between construction projects. This phase of the research focused upon the six members of the pharmaceutical division's management team. A three-stage approach to primary research was devised, comprising interviews, a focus group and a questionnaire. Firstly, each member of the management team was interviewed in order to identify their knowledge and experiences of pharmaceutical projects. The interviews were then analyzed to identify high-grade knowledge and recurring problems across pharmaceutical projects. Through further refinement, an agenda was drafted to form the basis for a knowledge-sharing focus group, which was facilitated by the academic collaborator in the research. According to Litosseliti (2003), focus groups "are small structured groups with selected participants, normally led by a moderator. They are set up in order to explore specific topics, and individuals' views and experiences, through group interaction." The management team participated in the focus group with aim of sharing knowledge and experiences in order to improve the delivery of pharmaceutical projects. Finally, a brief one page questionnaire was administered to all of the focus group participants in order to clarify a number of issues and to help with making recommendations for future KM activities within the division.

4.2.2 *Phase 2*

On of the main recommendations from Phase 1 was the need for the organization to conduct post-project reviews and document the lessons learned. With the collaborating practitioner's €100 million project having being recently completed, it was decided to focus upon the lessons learned on this project. The four main members of the project team were interviewed, comprising the Contracts Manager (also the collaborating practitioner), Site Agent, Site Foreman and the Building Services Engineer. The purpose of the interviews was to identify and document the main lessons learned from each individual's perspective. Following analysis of the interviews, the main lessons learned were identified and formed the basis for a post-project review session with the four project team members, again facilitated by the academic collaborator.

5 FINDINGS

5.1 *Case study 1*

The questionnaire was distributed to 180 professional and management staff via email, achieving a 36% response rate. As can be seen in Table 2, the survey respondents have a range of experience of working in the construction industry, with over a third having less than 5 years experience.

Conversely, 69% of the respondents have been working with the company for less than 5 years, which may be due to the migratory nature of the industry. Coupled with a relatively young workforce (63% are 35 or under), this low level of experience within the company highlights the need for effective LL practices to improve both the individuals and the organizations knowledge base.

Table 2. Survey respondents' industry experience.

	<5 years	5–10 years	11–20 years	>20 years	Total
Industry	37%	25%	14%	24%	100%
Case Study 1	69%	21%	8%	2%	100%

5.1.1 *Overview of lessons learned practices*

Based on the initial interview with a director, it was found that the company had implemented LL practices as part of the KM requirement for CPD accreditation, comprising a LL database (LLDB) and LL seminars. The LLDB is managed by the company's quality and administration manager on a part-time basis.

- Collection: chaired by a director, the company conducts a post-project review for all projects where key members of the project team discuss the best and worst experiences. The loss of experience due to time lapse is addressed by interim review meetings which are held every 6 months and "these would be reviewed as part of the end meeting . . . it's really at the end of the job that you look back and say 'what are the big issues here?'
- Analysis: following the review, the key LL are documented by the contracts manager in a standard template detailing the title, description of the LL and contact details for individuals involved, and classified based on the trade/subcontract package with which it is associated. Once completed, it is sent to the administrator, and if acceptable it is posted on the database, if not it may be sent back to the source for further clarification or edited by the administrator himself.
- Dissemination: the archived LL are disseminated via two methods, pull methods occur in the form of a LL database (LLDB), a central repository which can be accessed from all offices and sites by logging into the company's network, the use of which is not measured and tracked by management. The company director acknowledges that "you are depending on people to take the time to look at the database. We also give seminars based on lessons learned on a fairly regular basis to support the database." In conjunction with the HR department, the LL administrator organises LL seminars based on a selected trade or subcontract packages for staff, which are usually delivered in the Dublin office in the evening time.

5.1.2 *Evaluation of lessons learned practices*

According to the director, "the theory is, and I'd be interested in the answer from your survey on this one, is that before you start a particular package you log onto the database and have a look, in the hope that you don't make the same mistake again."

Despite nearly three-quarters of the survey respondents (74%) stating that they found it beneficial to

Table 3. Frequency of use of LLDB.

Rank	Use of LLDB	%
1	Very rarely	34
2	When I have a specific query/problem	27
3	Never	15
4	Quite often	13
5	When a new subcontract package starts	11

them in their work, Table 3 shows that very rarely ranked highest in terms of usage, with when a new subcontract package starts ranking lowest at 11%. During the interviews, the use of the LLDB was discussed, the following being the most pertinent issues identified:

– Lack of time: many respondents stated that they just didn't have the time to look through the database every time a new package started. According to the Site Manager: "I haven't checked it in about a year . . . you don't get time to, unless you're sitting here twiddling your thumbs . . . it's extremely difficult when you're out on site all day."
– Relevance to current role: some people questioned the actual relevance of LL to them in their current position. The Senior Engineer stated "a lot of the things on the lessons learned are relevant to foreman . . . they're the guys out there dealing with those issues . . . that's where the breakdown is, the people who really need to know don't have access to a computer, its not in their job description."
– No requirement to contribute: many people stated that there was no requirement on them to contribute to the LLDB, and as a result, didn't bother. The Senior Quantity Surveyor suggested "perhaps contributing to the lessons learned should be part of your work. The company I worked for in England did that, when you did your monthly report for the directors, you had to do your lessons learned."
– Difficulty finding the most recent lessons: the lessons are not sorted by date, which the Project Manager found to be quite frustrating, "you have to sift through the older lessons as well." Indeed, 42% of the survey respondents ranked this issue as the most problematic factor in using the database.

In considering how to improve the use of the LLDB a number of the interviewees contended that there should be refresher courses run, as most people felt that being shown how to use the LLDB on their first day with the company was not effective.

The LL seminars provided by the company can contribute to the staff's CPD requirements imposed by a variety of professional bodies, offering incentive for staff to attend. The survey found that 8% of respondents don't attend any seminars, 53% attend between 1 and 4, 31% attend between 5 and 9, with 8% attending 10 or more seminars each year. A number of problems with the seminars were identified in the interviews as:

– Timing and location of seminars: the seminars are run in the evening in the Dublin office, after a "hard day's work on-site." Many of the interviewees cited fatigue and long travelling times as being counterproductive to getting any value out of the seminars. According to one of the Foremen, "we were out working in the rain one day, a big concrete pour . . . and then I'm into this thing at 5.30 . . . and I mean the heat and all, I'd been out in the fresh air all day, out in the wind, and I come into this nice, cosy, comfortable room to a guy in a shirt and tie . . . and I'm gone!" The Contracts Manager suggested that "there should be more done on-site, particularly on a big site like this where you have a lot of staff . . . it's not a thing that has to happen in head office."
– Delivery of seminars: the Senior Foreman felt that the delivery of the seminars was problematic, "the likes of the office people would be giving a seminar on lessons learned . . . they talk about them, but because they're not involved on site, they don't come up with any solutions."
– Relevance: it is important that seminars are pitched at the right level to the audience "if it's not relevant or you know it already, you're going to switch off," a recurring theme in the interviews, people cited this aspect as putting them off attending again.
– Experience of attendees: a graduate engineer felt that they didn't gain a lot from seminars covering issues they hadn't yet encountered on site. "Once you've seen it been done, I find it's easier to go to a seminar and talk about it . . . it's hard to visualise something that you've never seen or experienced when you go into a room and listen to someone talk about it for an hour."

5.2 *Case study 2*

5.2.1 *Phase 1: Knowledge sharing across projects*

During the interviews, the respondents discussed a range of issues relating to cleanrooms including, finishes, services, the appointment of specialist contractors and commissioning and validation. A wide variety of problems have been encountered by the respondents in managing the construction of cleanrooms in areas such as floor, wall and ceiling finishes, the application of silicone, the integration of services into a cleanroom environment, services design and installation, ducting layouts, and setting and maintaining pressures. It was acknowledged by all that knowledge sharing within the pharmaceutical division was relatively informal and that through a more formal approach, the delivery of cleanroom projects could be improved. Site visits, a bi-annual knowledge sharing forum and the use of the company's intranet for documenting experience were suggested as tools for sharing knowledge.

There have been ad-hoc attempts by a number of the interviewees to conduct project reviews and document the lessons learned, but with little success. There was a consensus that a more formal approach to KM was needed within the division in order to develop and maintain a competitive advantage over rival contractors. The division's Director felt that "by standardizing the way we do things, we can reduce mistakes and demonstrate our expertise to clients and design teams."

Based on the interviews findings, an agenda was developed for the focus group with particular emphasis on the appointment of the cleanroom contractor, recurring cleanroom design and quality issues, commissioning and validation, the company's role as a management contractor, and the development of KM within the pharmaceutical division. Through facilitated discussion, the high-grade knowledge identified in the interviews was further refined and consolidated during the course of the focus group. The main issues identified and agreed upon during the focus group included:

– Based on previous experience, the cleanroom contractor needs to be appointed as early as possible.
– Best practice guidelines should be developed for the construction of cleanrooms to include consideration of finishes and services.
– The division lacks expertise in the highly specialized area of commissioning and validation. The company should seek to recruit expertise in this area and provide training for existing staff.
– A standard agenda for pre-construction commissioning and validation meetings should be drafted to include: scope, strategy, schedule and critical path, sequence of critical items and systems, design documents, procedures and personnel involved, approval sequences, documentation contents and system boundaries.
– Formal KM procedures need to be developed within the division, incorporating regular knowledge sharing sessions in the form of a focus group.

The main purpose of the questionnaire was to evaluate the focus group as a framework for knowledge sharing within the pharmaceutical division. All participants agreed that the focus group was of benefit to them and that they had learned a lot from such an approach to sharing knowledge. They were unanimous in their view that such an activity should become a regular occurrence within the pharmaceutical division. In order for this to happen it was suggested that a strategy for KM should be developed and agreed, and an agenda developed for the focus groups on relevant/specific topics. One of the participants suggested that depending on the topics, other key people within the division should attend, including building services engineers, foremen etc. Again all felt that knowledge sharing methods such as the focus group, lessons learned, email alerts and site visits could improve the delivery of Pharma projects, with one of the Senior Contracts Managers stating that any major conclusions derived from such activities should be "taken forward as policy." In order to improve the knowledge stocks of the division, training in the area of cleanrooms and particularly commissioning and validation should be provided for staff.

5.2.2 *Phase 2: lessons learned*

For the second phase of Case Study 2, the focus was upon capturing the lessons learned on a €100 million pharmaceutical project. The interviews with the four members of the project teams sought to identify the main lessons learned on the project from their own perspective. Current and potential knowledge sharing activities were also discussed in order to aid the development of the framework for capturing and sharing knowledge. A number of technical and management issues were identified by the participants including cleanroom finishes; services integration; commissioning and validation; handover and snagging. All interviewees agreed that there was a need for improved sharing of knowledge within the pharmaceutical division and the wider organization. Only the Contracts Manager had more than a passing knowledge of other ongoing pharmaceutical projects within the organization.

With a wide variety of issues identified, these were consolidated and refined into an agenda for a post-project reviews meeting, in the form of a focus group. The aim of the session, which lasted for approximately two hours, was to consolidate the individual team members learning and identify the main lessons learned on the project. These included:

– Cleanroom wall panels need to be properly protected.
– A template should be made for cutouts in the walls as considerable time and money was spent on repairs.
– A 1200 mm $\times$ 600 mm grid system is the preferred option for a walk-on ceiling.
– The company need to consider the extent of silicone sealing required when pricing a job.
– A recommended list of light fittings, filters and sprinkler heads needs to be identified, as a number of these were found to be incompatible with the ceiling system.
– The HVAC system's capacity and efficiency should be checked during design.
– A clear protocol should be agreed with the client for commissioning and testing of alarms and the building management system
– The commissioning contractor needs to appointed as early as possible and a window left in the programme for getting the system up and running, and testing it.

– Procedures should be developed for people working in areas that have been handed over to the client.
– A strategy for snagging needs to be agreed with all subcontractors, the client and design team.

At the end of the focus group, all participants agreed that they had learned a lot form one another and that a post-project review should be undertaken after every project. Based on the post-project review, a LL report was composed which included a title, project details, contact details for the project team. The actual lessons were categorized under a number of key headings including flooring, walls, ceilings, use of silicone, lighting, sprinkler heads, HVAC, alarms, services integration, commissioning & validation, handover of phased work and snagging. The next phase of the action research shall seek to develop and refine the format for LL dissemination on the company's intranet, through the development of CPD and training resources and integration of some LL into company policy.

6 DISCUSSION

While the need for construction organisations to adopt formal KM practices is well recognised, the project-based, temporal nature of the industry presents significant challenges in this regard. The adoption of lessons learned practices as part of KM can be used to capture valuable knowledge from construction projects which can then be shared with the wider organization. Indeed from an Irish perspective, the country's leading professional body has included the use of such KM systems in the criteria for their CPD accreditation scheme. In this context the research reported in this paper seeks to identify, evaluate and improve LL practices, within two of the leading Irish construction organizations, leading to the development of a framework for capturing and sharing construction project knowledge.

6.1 *Collection*

It is acknowledged by Disterer (2002) that the identification and capture of LL is an extremely difficult process. Indeed the Director from Case Study 1 feels that it is realistic that only the big lessons from the project will be captured at the end of a project. The post-project review appears to be one of the most popular methods of collecting LL, hence its use during Case Study 2, albeit in the form of a focus group. The sought input type collection process as identified by Fisher et al. (1998) seems to be the best method for collecting LL, although the Senior Quantity Surveyor from Case Study 1 spoke about a previous employer who required staff to submit LL as part of their reporting duties. In order for the collection of LL to be effective, the support of senior management in providing time and resources for the project team to review the project is vital. Getting the key members of the project team to participate is highly important as it provides a multi-faceted, in-depth view of the project. The collective knowledge of the participants in phase 2 of Case Study 2 allowed for their different perspectives to enhance the robustness of the LL.

6.2 *Analysis*

Once captured, the LL must be analysed to ensure that they are factually correct, as unsound LL are likely to be rejected by construction professionals. Furthermore, the documentation of LL requires consideration of the title; information on its source and context; and its classification for easy retrieval (Kartam 1996). Case Study 1, have a dedicated manager for their LL practices, and all LL are entered into a standard template. Having developed a template for LL in Case Study 2, it is now intended to evaluate this with staff within the pharmaceutical division.

6.3 *Dissemination*

One of the biggest challenges in disseminating LL through pull methods such as a database is the distribution gap as identified by Weber and Aha (2002). This was evident within Case Study 1 who had implemented a LLDB, where the Director acknowledged this problem. Almost half of the survey respondents (49%) stated that they use the LLDB very rarely or never, highlighting the need for human intermediaries (i.e. managers) to monitor and review their staff's use of the LLDB. The interviews revealed that staff didn't have time to search the LLDB, felt that the lessons weren't relevant to them, and there was no requirement on them to use it. The survey and interviews with staff found that there are problems in searching and retrieving LL from the database. The need to retrieve the lesson quickly and by multiple parameters is something that Kartam (1996) identifies as being a key component of LL practices. Case Study 1 recognised that there were problems with dissemination and developed training seminars based on LL which were delivered to staff in the evening time. Again, there were a number of problems with the seminars including the timing and location, delivery, relevance and experience of attendees. As well as using LL for training, Davidson (2006) suggests that they should be incorporated into business processes, and be used to develop checklists. The findings from Phase 1 of Case Study identified a number of potentially useful methods for disseminating LL including, site visits, regular knowledge-sharing focus groups between projects, documented LL on the company intranet and regular email alerts. Both phases of Case Study 2 viewed the need for certain LL to be integrated into business processes, such as best practice guidelines, standard agendas, recommended lists and working protocols and strategies.

Both Case Study 1 and the literature reviewed have shown that there is potential to align CPD with LL practices. In order to redress the distribution gap, the use of capture knowledge in the form of LL could potentially be used to form the basis of training activities within an organisation. By linking LL to CPD, professionals could meet the requirements of their professional body, while organisations could benefit from a more knowledgeable and effective workforce.

7 EMERGING FRAMEWORK

Despite the significant challenges involved in attempting to implement LL practices, they are considered to be a worthwhile undertaking for construction organisations. Case Study 1 reinforced some of the challenges highlighted in the literature, while Case Study 2 sought to improve upon the implementation of LL practices. Based on the research undertaken, a lessons learned process has been developed which seeks to optimise the combination of both codification and personalisation strategies. As can be seen in Table 4, throughout the various stages of the process, different participants and activities are involved. LL should be collected at the end of construction projects but also on an ongoing basis through knowledge-sharing focus groups, similar to the one conducted during the first phase of Case Study 2. The LL should then be recorded on a standard template and analysed by an individual with designated responsibility for LL. During analysis, the dissemination of the LL should be considered. For example, some LL may indicate a need to change existing company policy, while others may be so important that they should be disseminated via e-mail to relevant staff. While many of the LL will be posted upon a LLDB/intranet, their use as training material should also be considered to make dissemination more effective.

Having considered the LL process, it is now worth considering the wider context of LL practices within construction organisations and the framework which has emerged. This framework (see Figure 1) proposes that there are three key stakeholders in LL practices; the individual, the organisation and the professional body. By adopting the LL process in Table 4, construction organisations can provide a range of activities which may contribute to an individuals CPD, whilst capturing and sharing valuable construction project knowledge. Individual professionals may be more inclined to participate and engage in such activities if they are recognised by the professional bodies of which they are members. Ultimately, such an approach could lead to a win-win situation for employers and staff, with improved performance for both parties.

Table 4. Lessons learned process.

	Collection	Analysis	Dissemination
Participant	Project Teams	LL Manager	All Staff
Objective	Capture LL	Verify LL	Share LL
Activities	– Post-Project Review – Knowledge Sharing Focus Group	– Standard Template (title, project details, contacts, LL)	– Training – E-mail Alerts – Policy – LLDB/Intranet

Figure 1. Emerging lessons learned framework.

8 CONCLUSIONS

If construction organizations wish to improve their performance, they need to consider a formal approach to capturing and sharing valuable construction project knowledge. Lessons learned practices are quite important in this regard and the process of collecting, analyzing and disseminating these lessons can prove to be quite a challenge. One of the most popular approaches is to store captured lessons on a repository, with the onus on individuals to seek relevant lessons when required. However the primary research confirmed the presence of a "distribution gap" which had been identified in the literature. It would appear that while there is merit in codifying lessons learned, that the dissemination of them requires careful consideration. The emerging framework proposes that lessons learned be integrated into CPD activities provided by the organization, thus allowing individual staff to maintain their membership of professional bodies. Furthermore, the dissemination of certain lessons learned should be undertaken by becoming part of company policy.

Another key consideration is the relevance of the lessons learned to individual staff, that is, an individual's role and/or level of experience may have an impact upon their knowledge requirements. The next phase of the research will seek to develop further the integration lessons learned with CPD whilst differentiating between different roles and levels of experience.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

The evaluation of health and safety training through e-learning

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ABSTRACT: The construction sector is the worlds largest industry with 111 million people employed world wide. There is a clear need to address health and safety training through innovative methods such as e-learning. This paper reports on the progress of an ongoing Socrates Minerva project which aims to create an instructional design frame work for using virtual classes to deliver health and safety training to construction professionals.

The project is in the process of delivering health and safety training to construction professionals through out Europe using virtual classes. The virtual classes are designed using the theory of Multiple Intelligence (MI) with which postulates that different individuals can have different learning styles. Translating MI principles from a traditional classroom to an e-learning environment represents a new and challenging initiative. In order to measure the effectiveness of the virtual classes being delivered an evaluation questionnaire has been developed in order to measure participants' satisfaction levels.

This paper justifies the need for an evaluation process as part of the action research methodology and outlines the key areas in a virtual class environment that effect participant satisfaction levels. Virtual classes have the potential to make a large impact on the way training is delivered in the future. The adaption of MI theory for use in a virtual class frame work, has considerable potential for successful training in the construction industry.

1 INTRODUCTION

Throughout the EU there is recognition that the standards of occupational health and safety have to be improved. Each year about 1300 people are killed and a further 800,000 are injured (CSO, 2006). Its makes moral, financial and legal sense to take actions to increase health and safety awareness in the construction industry.

One of the key initiatives that can make a positive impact on improved health and safety statistics is education and training. The project proposes the innovate use of virtual classes to deliver health and safety training in the construction industry.

2 DESCRIPTION OF PROJECT

This project is a network of organisations who have secured funding through the Socrates Minerva Action body. The organisations involved include Nottingham Trent University in the UK, Istanbul Technical University in Turkey, Universite de Nice Sophia-Antipolis in France, Centre for the Advancement of Research and Development in Educational Technology in Cyprus, Multimedia Instructional Design, Blended Learning Design and Waterford Institute of Technology in Ireland. The Irish, Turkish and UK partners provide the specific construction expertise.

The specific objectives that the network of partners is attempting to meet include:

– Identify multiple intelligence instructional principles for the design of virtual classes
– Design a series of virtual classes so that class design skills using multiple intelligence tenets are acquired by all partners
– Enable each partner to design, deliver, record, edit and archive its own virtual class, for an audience comprising all other partners and their chosen pilot student populations
– Use and develop an on-learning resource dedicated to improving the health and safety record of the construction industry

– Disseminate the results of the project to all interested EU parties.

3 TECHNOLOGY AND LEARNING

The use of advanced information and communication technologies (ICT) are now regarded as the future direction of innovative educational institutions (Chung and Shen, 2006). The use of these technologies has the potential to alter the space and time constraints of traditional instructional activities.

A virtual classroom has been defined as: *an online learning and teaching environment that facilitates the collaboration and integration of discussion forums, chat rooms, quiz management, lecture notes and assignment repositories, subscription services, relevant web links, email distribution lists and desk top video conferencing into a conventional lecture based system*(Chye Seng and Al-Hawamdeh, 2001)

For educational institutions and for workplace based learning, online environments are rapidly expanding as a channel for the delivery of learning (Chye Seng and Al-Hawamdeh, 2001). The use of a virtual class offers greater efficiency in training delivery, supports a greater diversity of approaches, increases flexibility for learners and offers extensive interaction (Bower, 2006). While the use of virtual classes can enhance the conventional learning experience the most critical part of online learning is its ability to foster interaction – student to student and instructor to student (Davis and Wong, 2007).

4 MULTIPLE INTELLIGENCE FRAMEWORK

The *Multiple Intelligences* (MI) framework was introduced by Howard Gardner of Harvard University in the early 1980s. It postulated that individuals possess several independent learning styles ('intelligences'). Gardner defined intelligence as the capacity to solve problems or to fashion products that are valued in one or more cultural settings (Gardner, 1983). Cantu (2000) argues that the key to the successful dissemination of Gardner's MI model was that it is not a prescriptive model, but instead an approach to teaching and learning that allows for individual interpretation, design and implementation. The general premise to MI research is that different student learn differently and student experience higher levels of satisfaction and learning outcomes when there is a fit between a learner's learning style and a teaching style (Eom et al., 2006).

Gardner's eight intelligences are shown in table 1. Eachintelligence is matched with an example of an instructional activity which would be suitable for a virtual class.

Table 1. Possible instructional activities to be integrated with the Virtual Class (Acar et al., 2008).

Intelligence	Examples of instructional activities
Linguistic	Writing, editing, discussion (i.e., writing a set of instructions on identifying hazards, critique written resources such as relevant safety reports)
Logical/ mathematical	Analyzing relevant statistical data, creating graphic representations (charts, diagrams, etc.); devising a strategy to identify hazards of falls; conducting relevant measurements
Spatial/ Visual	Matching illustrations, photos or cartoons with corresponding subject categories; creating/evaluating site layouts (i.e.' safe workplaces')
Bodily/ Kinesthetic	Simulations, analysis of workspace/site ergonomics
Musical/ Rhythmic	Audio visual elements, designing PowerPoint presentations which incorporate music and visual elements
Naturalistic	Computer simulated spaces/environments, cities, maps, illustrations, etc.
Interpersonal	Activities that might be designed to incorporate cooperative learning groups
Intrapersonal	Activities that might be completed through reflective individual projects

5 RESEARCH METHODOLOGY

A case study methodology has been used as part of the empirical approach to evaluating and deploying the recourses used for health and safety training in the construction area. The case study approach as a research strategy can be used in different situations to contribute to knowledge of individual, group, organisation, social, political and related phenomena according to Yin, 2003, cited in (Wall et al., 2007).

The development and refinement of the research phases are based on an action research methodology. An action research methodology aims to solve current practical problems while expanding specific knowledge (Baskerville and Myers, 2004). Put simply action research is essentially "learning by doing". The cycles of action research are illustrated in figure 1. As there has been little research on the development of an educational framework for virtual classes the action research methodology allows for refinement and development of an education framework.

Action research provides a method to explain why things work or don't not work, this is particularly useful in the development, implementation, and assessment of the virtual classes. The underlying philosophy is one of pragmatism, a process that concentrates on asking

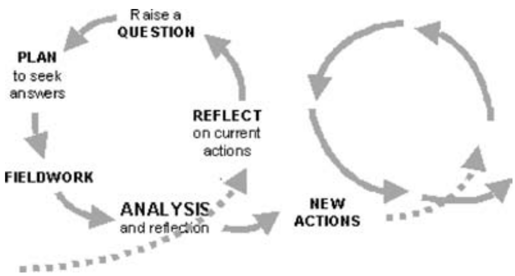

Figure 1. The cycles of action research (Wall et al., 2007).

the right questions and then getting empirical answers to those questions.(Baskerville and Myers, 2004).

The action research methodology allows for the involvement of external and internal research elements (Wall et al., 2007). It is anticipated that internal sources will involve the on-going evaluation and testing by project members at all stages of development, the involvement of groups of students at partner institutions from a construction discipline and the comparison of the experience of e-learning and health and safety across the project partners areas of expertise. The external research sources involve the participation of relevant academics in the final evaluation of the technologies used in the delivery of the virtual classes and the learning that took place.

Action research allows for collected data to be used immediately, problems that are identified through the data collection process can be analysed and alternative actions can be developed and tested (Figl et al., 2005). It allows for a methodology which can deal with the complex and dynamic nature of real word situations (Avison et al., 1999), such as delivering virtual classes on construction health and safety.

Action research can be seen as a two stage process. The first a diagnostic stage which involves collaborative analysis of the research focus by the researcher. The second is the therapeutic stage which involves collaborative change. In this stage change can be introduced and the effects studied (Baskerville and Myers, 2004). The research phases used on the project are discussed following sections:

5.1 *Phase one*

In order to test the theoretical virtual class framework developed by the project members a pilot phase was developed. The virtual class was ran with a group of students in Waterford Institute of Technology. The content of the class was the identification of hazards to falling from height on a construction site.

The virtual class used a server based learning management system (LMS) to host the asynchronous educational content and control the student's access. A web based collaboration system called Dim Dim was used to host the synchronous interaction between the instructor, the students and the content. The content hosted on the LMS was focused on a Adobe Flash 'Core Graphic'. The core graphic as a image of a construction site with built in interaction which allowed students to identify hazards in the context in which they would occur. Figure 2 is a static image of the interactive 'core graphic' used in the class.

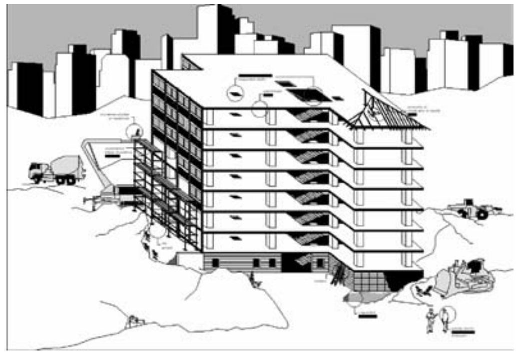

Figure 2. The 'Core Graphic' (Acar et al., 2008).

The only questions completed by the students at this stage were a pre and post test. This was a simple test which tested the students' knowledge of the content before and after they completed the virtual class. It is a mechanism of testing the primary purpose of the virtual class – to teach the students the learning objectives.

The running of the pilot phase experienced a number of technological problems. In order for the web based collaborative software Dim Dim to operate the latest version of Adobe Flash had to be installed which caused problems for some students. The pre and post test questions which were asked before and after the virtual class provided inconclusive results. Following a discussion of the project partners it was concluded that the learning out come of the falls from height class was essentially a behavioural change and the use of a quiz was not an appropriate way to measure that any change which may have taken place. The pre and post test results did provide a useful picture of the students' prior knowledge of health and safety in construction.

Due to the nature of the technology used in the virtual class a number of the project partners were all able to log into the pilot virtual class as it took place. For those unable to participate in the class was recorded and made available as an archive.

5.2 *Phase two*

The experience of running the pilot virtual class is a valuable tool in completing the second phase of the virtual class delivery. The next phase will involved sections that cover 4 subject areas; Indentifying the

Table 2. The virtual classes titles.

Title of virtual class	The virtual class participants
Indentifying the hazards of working at height	Waterford Institute of Technology Students
The consequences of falls from height	Waterford Institute of Technology Students
The use of mobile work platforms	Istanbul Technical University Students
The use of scaffolds	Istanbul Technical University Students
The formulation of a personal method statement	Nottingham Trent University Students

hazards of working at height, the consequences of falls from height, the use of mobile work platforms, and the use of scaffolds. The final virtual class is a section called the formulation of a personal method statement. The idea is that students have a chance to collect the information they have being given over the previous four sections and formulate into a personal statement that they could identify with. This is inline with the MI approach to education where learners are encouraged to construct their own knowledge. It is also useful when attempting to teach something which essentially is a behavioural issue such as heath and safety on a construction site. The titles of the virtual classes and the educational institution that will host them are listed in table two.

Based on the experience of the pilot phase a guide was developed for the technologies used in delivering the virtual class. The research plans to deliver the sections to students in Ireland the UK and Turkey. Each class will be recorded and archived and made available as a learning resource to the next group of students.

As this phase of research is part of the action research methodology, an evaluation system is needed to feed information into the next phase of the virtual class development. One of the key aspects in the use of virtual class is learner satisfaction levels (Eom et al., 2006). In order to measure this, a questionnaire that the students will fill out upon completing the virtual class is needed. The aim of the questionnaire is to provide an insight into participant's satisfaction levels in the different aspects of the virtual class experience.

6 EVALUATION FRAMEWORK.

The purpose of this evaluation is to provide a mechanism to measure the student's satisfaction of the virtual class and use the information to improve the virtual class framework. The evaluation is to focus on the headings seen in figure 3. Each heading is a key factor

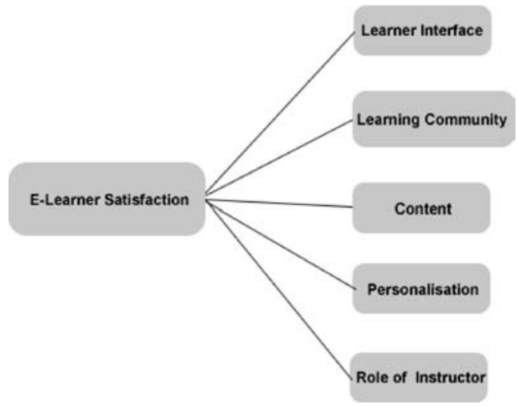

Figure 3. The Factors to E-learners Satisfaction.

in achieving learner satisfaction in a virtual class. It is proposed that participants in the projects virtual classes will fill out a likert scale questionnaire on key elements shown in the following section.

6.1 *Learner interface*

The learner interface is the technological interface used during a virtual class (Chye Seng and Al-Hawamdeh, 2001). For this project there were two web browser based learner interface technologies used. The LMS used to host and control the asynchronous educational material was called Moodle. Moodle is an open source LMS that is inexpensive and easily adaptable to the projects needs. A web browser based collaboration system called Dim Dim was chosen to host the synchronous interactions of the virtual class. The project proposed that Moodle and Dim Dim provide a complete system to host and deliver the virtual class to a group of remote access students.

The features used in the Moodle LMS include assigning each student which a username and password and giving them access to the educational content on the class webpage. The class webpage should be easy to find and navigate through. One of the aspects of incorporating MI principles into a virtual class is trying to keep the webpage as simple and visual as possible. By taking into account that people have different ability levels in using the technological interface and designing the interface in a simple and visual way is achieving some of the MI principles.

In terms of the web based LMS the evaluation should ask participants to rate the following features;

- The ability of participants to log onto the web based LMS
- The ability of participants to navigate the LMS
- The LMS ease of use
- The stability of the LMSs' operation

The synchronous technology used to present the virtual class was called Dim Dim. The evaluation should cover the following areas;

– The ease of use and stability of Dim Dim
– The clarity of audio and interactive presentations through Dim Dim
– The chat features
– The shared microphone features
– The shared whiteboard features
– The application sharing features
– The use of class polls

6.2 *Learning community*

One of the key success factors of any virtual class is its ability to create and sustain a learning community. The social aspect to education is the most important one and can be used by the instructor in the transfer of skills and information (Palloff and Pratt, 2005). Research suggests that an interactive instruction style and high levels of learner to instructor interaction results in high levels of learner satisfaction (Eom et al., 2006). Given the nature of virtual classes, in that the participants are geographically separated from each other, active learning communities can be beneficial in sustaining participants self motivation (Palloff and Pratt, 2005). The Moodle LMS is based on a educational philosophy called social constructivism which postulates that students learn best when forming their own knowledge in a social environment.

Moodle has therefore incorporated a number of learning community tools into its LMS. Each class can be assigned a forum where all participants can post discussion items and ask questions. Well managed forums have proved to been a highly effective tool to building communities and providing effective learning as participants have time to read the contributions and make their own. The Dim Dim collaboration system has the ability to share voice, text and PowerPoint presentations in real time. This is a powerful tool that allows the dynamic of a traditional class to take place among a remote group of participants.

In terms of the learning community the evaluation should ask participants to rate the following features;

– The ability of the learners to interact with each other
– The ability of learners to interact with the instructor
– The ability to share knowledge with the rest of the participants.

6.3 *Content*

The presentation of education class content in a virtual class has an impact on learners satisfaction of the virtual class (Eom et al., 2006). Being aware of learners varied learning styles as identified by Gardner's MI theory allows content to be presented in ways that are accessible to as many learning styles as possible. The project uses the interactive 'core graphic' to present the content in each virtual class. This 'core graphic' allows for information to be presented visually in the context of a construction site and can be controlled by the individual learner.

Gardner points to five major learning styles he calls multiple entry points (Gardner, 1983). By presenting content through the five multiple entry points Gardner's sees the content as being accessible to a variety of learners with different intelligence make up.

The evaluation should ask participants to rate the following areas;

– The content as been presented in a clear and understandable way
– Content presented through a case study or narrative
– Content presented through diagrams or pictures
– The level of content interactivity
– Content presented through forums, web chats and real time instruction
– The usefulness of the archived content.

6.4 *Personalisation*

This refers to the degree to which the learner can control the learning process. As virtual classes place more responsibility on the learner then traditional education (Eom et al., 2006) it is important that learners have the tools they need to self-manage the learning process. The personalisation of an educational approach important as learners control and actively influence their learning activities and understanding. In order to achieve a level of personalisation learners should be given opportunities to maintain their individual creativity and autonomy in the projects and assignments they complete (Fisher and Baird, 2005).

In terms of personalisation the evaluation should ask participants to rate the following features;

– Their ability to access the content they need
– Their ability to choose what they want to learn
– Their ability to control the learning process
– The degree to which the virtual class records their learning progress and performance.

6.5 *Role of the instructor*

The role of the instructor is the most important element of a virtual class (Eom et al., 2006). The instructor is key to any educational situation – in the context of a virtual class there are significant changes the traditional model which requires a change in role from the instructor. In a virtual class the instructor must balance activities that will foster social motivation with providing learners with the information and knowledge they require (Fisher and Baird, 2005). The change in a virtual class environment is that the professor and students are members of a community of learners where the instructors role shifts from lead speaker to that of a facilitator (Yang and Cornelious, 2005). Due to the need for increased levels of student self motivation the instructor plays more of a support role to the remote class of learners. The awareness learning styles as seen in MI theory are an important aspect as they allow instructors to

In terms of the role of the instructor the evaluation should ask participants to rate the following features;

- The level of interaction learner had with instructor
- The degree to which the learner seen the instructor as a
  - Motivator
  - Facilitator
  - Lead Speaker.

7 CONCLUSION

The evaluation process is a key part of the methodology as it allows the action research to take place resulting in the development of the virtual class frame work. This is the stated aim of the research.

The construction industry is the largest industry in the world. It is also the most dangerous and complex. The construction industry could benefit from innovative training in the area of health and safety. The use of virtual classes to deliver health and safety training represents an innovative approach to finding a solution to the health and safety problems of the construction industry. This is an area which uses new technologies to attempt to solve a complex problem and the results are behavioural based which are difficult to measure. This requires a research methodology that is flexible and can accommodate the complexity and dynamic environment that the construction industry and online education exist in. A case study and action research methodology allow for the flexibility needed. One of the key elements to a successful action research methodology is the ability to evaluate the case study and use the information gained to develop and refine the research model. As this research targets teaching students construction related health and safety an evaluation system has been developed to measure the students' satisfaction levels of the virtual class experience as a whole. With the formulation of a sound evaluation process the results gathered through that process can be seen as a true picture of the overall effectiveness of the virtual classes been delivered. The evaluation results will guide the future delivery and development of the virtual classes delivered through the project. The findings of this research should be useful to those delivering education in a virtual class environment, to those carrying out research in the area, and to those working in construction health and safety.

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Implementing eCommerce in the Irish construction industry

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ABSTRACT: The current methods of ordering, delivering and invoicing of materials in the construction industry is enormously inefficient, with vast quantities of paperwork, duplication of effort, scanning, re-keying and resolving mismatches between invoices, delivery dockets and purchase orders. The objective of this paper is to set out the progress that is being made by the Construction IT Alliance (CITA) in Ireland to support the implementation of eCommerce in the Irish construction industry. The authors will present the result of a pilot project in 2006 which demonstrated that the technology necessary for implementing an electronic supply chain exists and could be deployed successfully in the construction industry. The authors also outline the expected results following the recent setting up of a dedicated eCommerce group by CITA to provide independent advice and support to the members that are embarking on implementing eCommerce. An additional expected result outlined by the authors includes the implementation of a standard data pool to facilitate the interoperable exchange of product codes between trading partners.

1 INTRODUCTION

Over recent decades, industry generally has come to recognise the inefficiencies that exist in paper-based systems. Many sectors of industry have replaced their paper-based systems with electronic systems. The construction sector, however, lags behind other business sectors in harnessing the greater potential of Information Communications Technology (ICT) (Thomas and Hore, 2003; Gunnigan et al., 2004; Hore and West, 2005a).

Building materials can account for up to 50% of all costs on a typical construction project (Tavakoli and Kakalia, 1993). There are many millions of trading documents produced by both main contractors and suppliers, such as purchase requisitions, purchase orders, delivery notes, supplier invoices, supplier statements and remittance advice notes (DoF, 2002). Each of these documents has to be re-keyed individually as they pass between different locations and computer applications (Hore et al., 2004).

Apart from the obvious inefficiencies of this process, there is also a high risk of error, and in the case of documents such as PODs (Proof of Delivery), a figure of 25% of PODs lost on construction sites is not an uncommon figure. The retail and electronics industries have been using an electronic supply chain exchanging various documents for twenty years or more, but the construction industry has been slow to adopt this technology, mainly because of the nature of the work undertaken, and the temporary nature of construction sites.

This paper will present the methodology and results of a pilot project which sought to re-engineer the purchasing process, by seeking to adopt a fully integrated ICT solution, which achieved a dramatic improvement in the overall levels of productivity with subsequent cost reduction. The paper goes on to describe the expected results following the recent setting up of a dedicated eCommerce group by CITA to provide independent advice and support to the members that are embarking on implementing eCommerce.

CITA is an organisation dedicated to the promotion of best practice in the use of ICT in the Irish construction industry. It was established originally by the Dublin Institute of Technology, but has since evolved into a company limited by guarantee with a membership of over 140 organisations drawn from main contractors, suppliers, architectural practices, quantity surveyors, engineers, project managers, and third level institutions.

2 TRADITIONAL CONSTRUCTION MATERIAL PURCHASING PROCEDURES

The traditional process of procuring materials in construction is dependent on a number of factors. For

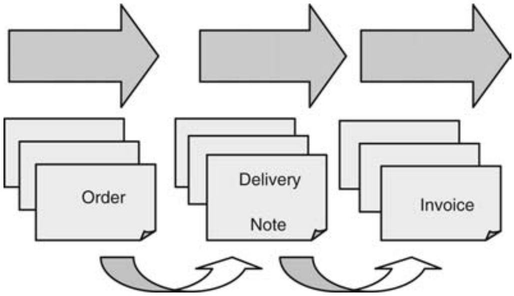

Figure 1. Traditional material procurement process.

example, the size of the project, size of firm, organisation structure of the firm and the roles and responsibilities of the employees within that organisation can dictate purchasing procedures. The process typically involves both centralised and decentralised personnel. The sophistication of the process varies widely, with many of the more established firms possessing company manuals detailing the procedures and standard forms that staff should adopt (Canter, 1993).

Figure 1 depicts an outline of the material purchasing process during the construction stage.

Purchasing procedures typically involve a paper-based communication process between the purchaser and supplier. It invariably involves the raising of a purchase order (PO) to the supplier. On delivery of the materials to site, a delivery docket is signed by the contractor and forwarded to head office as proof of delivery. Payment of the invoice will be made following the matching of the invoice to the original purchase order and signed delivery docket.

Classic purchasing processes in construction are paper-based, where documents are used to create other documents. As a result, the probability of an error increases as information is transcribed from one document to another. Although paper documents can be inputted into a computer system, data entry requires multiple transcriptions of the data. As a result, such processes can result in the introduction of additional errors into the system (Hore and West, 2005b). Paper-based systems also are dependent on ensuring that all appropriate departments get copies of the documents necessary to do their job. If even a small percentage of those documents become lost or misplaced, there can be gaps and delays in the system (O'Leary, 2000).

3 THE PILOT PROJECT

The overall aim of the pilot project was to re-engineer the purchasing process within a contractor's organisation, by enabling an electronic three-way match of the PO, delivery docket and invoice data, thus enabling a significant improvement in both productivity and overall administration costs per transaction.

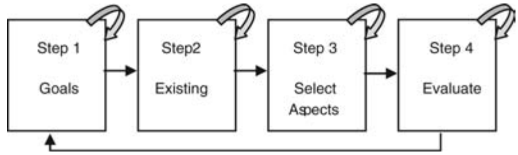

Figure 2. Re-engineering methodology adopted in 2005 pilot project (Li, 1996).

The methodology involved using the re-engineering methodology designed by Li (1996). Li suggested that at all stages in the re-engineering process it was important to introduce an experimental loop, in order to ensure the progression of problem solving during the re-design of the business processes. This methodology is illustrated in Fig. 2.

The process designed by Li (1996) involved four core stages, namely:

Stage 1 – Set goals for re-engineering – This stage involved the setting of clear and measurable objectives at the outset of the re-engineering process.

Stage 2 – Analyse existing processes and its operational boundaries – In analysing the existing process, focus was directed to understanding the problems and inefficiencies that existed within the contractor's business process.

Stage 3 – Select aspects of the existing process to redesign – Fundamentally, the re-engineered solution devised by the authors involves a fully electronic, three-way electronic match of the PO, delivery docket and supplier invoice, minimising as many of the existing identified inefficiencies as possible, while solving any new problems that may arise. In this, the focus was the source of the PO information was singled out in re-designing the process. In addition tasks and activities that did not add value to the business process and were costly to administrate were simply removed.

Stage 4 – Implement and evaluate the new process – It was important that the new process was tested for a reasonable period of time. Results from the new process were collected and the evaluation of the results indicated that the re-engineering goals were achieved, as shall be shown.

The pilot project sought to identify goals, in order that a technological solution to the problems would effectively re-design and re-organise the purchasing process, which would lead to a worthwhile and tangible improvement in the performance and competitiveness of both trading partners. The specific goals identified by the pilot team included:

1. To document the current trading procedures utilised within the contractor's organisation.
2. To identify the inefficiencies that currently exists within the contracting organisation.

3 To re-design the purchasing process with a view to addressing the inefficiencies that currently exist.
4 To document the proposed trading processes and the ICT support infrastructure to be utilised between the contractor and the supplier on the intended pilot project.
5 To execute the proposed re-engineering process on a live project.

The authors carried out a detailed examination of the contractor's existing purchasing process. This involved mapping the process flow charts for the material ordering, material receiving and invoice processing. Following the completion of this exercise it was evident that many inefficiencies existed in the current process adopted by the contractor, namely:-

– Manual reliance – Most (if not all) of the purchasing process was manual, with little to no reliance on technology.
– Matching inefficiency – Two/three way matching of items leads to re-handling of paperwork many times until matching occurs, which increases the probability of errors occurring between the various documents for single transactions
– Deficient supplier information – Personnel can only collect a limited amount of information about suppliers and their products through the collection of physical catalogues. The catalogues, in turn, are cumbersome to use, require large storage areas and can quickly become out-of-date.
– Poor integration – The paper-based system was also dependent on ensuring that all appropriate departments obtain copies of the documents necessary to do their job. If a small percentage of those documents are delayed, lost or misplaced, there will be delays in the payment process as a whole.

In re-designing the contractor's purchasing process, it was necessary to look in detail at the remaining weaknesses in the process and identify the electronic opportunities to remove these weaknesses. The key to the solution was to allow the supplier to create the PO data, as opposed to the traditional role of the contractor creating the PO. By allowing the supplier to create the PO, delivery note and the invoice information, the problem of the three-way electronic match was much more likely to be solved.

The re-engineered process included a minimum amount of manual work to be carried out. This was limited to the creation of the Open Order, the necessity to approve the PO Confirmation and the electronic signature of the handheld device. There was no necessity to photocopy extensively or print documentation other than to receive the Open Order details initially. There was a requirement to allow interrogation of the Enterprise Resource Planning (ERP) system with limited re-keying of information with respect to PO, delivery note and invoice confirmations.

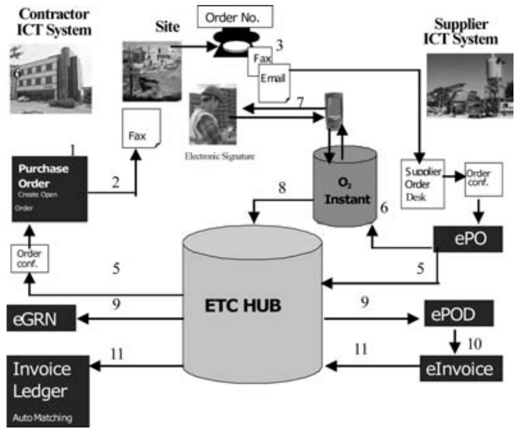

Figure 3. Proposed trading process and ICT infrastructure.

The proposed ICT infrastructure to be adopted involved the electronic transfer of PO, delivery notes and invoices via a central HUB. Figure 3 illustrates the ICT infrastructure.

The HUB was able to convert any incoming EDI, XML or spreadsheet documents from either the contractor's ERP system or the supplier ERP system into a format suitable to the particular receiving ICT system.

The proposal adopted involved the trading parties creating an Open Order in the contractor's ERP system (Step 1). In advance of this communication, the contractor would have negotiated a schedule of prices for particular products from the supplier. The proposed process created an automatic fax to site detailing a unique PO number (Step 2). The open order authorised site personnel to order materials by telephone, fax or email to the supplier (Step 3). The key difference between the initial proposal and the proposed solution was the fact that the supplier created the Electronic Purchase Order (ePO) information, not the contractor, as in the initial proposal (Step 4). The ePO was electronically sent to the HUB. The HUB converted the data into a XML message, which, in turn, is forwarded to the contractor's back-end database and populates a line item on the contractor's purchasing workbench (Step 5).

The ePO created by the supplier was dispatched to the O_2 Instant repository, which, in turn, routed the message to a handheld computer (Step 6). The supplier delivered the material to site and the contractor electronically signed the Personal Digital Assistant (PDA). The ePO is routed back to the O_2 Instant repository (Step 7) and onto the HUB to verify proof of delivery (Step 8). The ePOD is routed to both the contractor's and the supplier's back end database and populates line items in their respective ICT systems, thus creating an Electronic Goods Received Note (eGRN) (Step 9).

Table 1. Achievement of the pilot project objectives.

Pilot Project Objectives	Observations
To document the current trading procedures utilised within the contractor's organisation.	This was the first step in the re-engineering process. This involved mapping the process flow charts for the material ordering, material receiving and invoice processing.
To identify the inefficiencies that currently exist within the contracting organisation.	The key inefficiencies observed included manual work, re-keying of information and extensive photocopying.
To re-design the purchasing process with a view to addressing the inefficiencies that currently exist.	The focus for re-designing the process was the source of the PO information. The logic involved maintaining a single original sources for all purchasing document which would in turn allow for an electronic matching of the original PO, GRN and supplier invoice.
To document the proposed trading processes and the ICT support infrastructure to be utilised between the contractor and the supplier on the intended pilot project.	The proposed ICT infrastructure to be adopted involved the electronic transfer of PO, delivery notes and invoices via a central web-based repository.
To execute the proposed re-engineering process on a live project.	In total, there were 37 electronic transactions carried out in October and December 2006 between the contractor and the supplier, with a 100% success rating on the matching of the PO, delivery note and the invoice.

The receipt of the ePOD in the supplier's back-end system, will allow the supplier to create an eInvoice from the ePOD and ePO data (step 10). The supplier eInvoice is routed via the HUB to the contractor's invoice workbench on the ERP software (step 11).

While it is clear that the re-designed process has potential to remove the inefficiencies highlighted earlier, it was, nevertheless essential to test the process in a live site environment.

No particular lessons were identified by the contractor's parties, other than the fact that the pilot project results proved that the re-engineering concept and the technology worked. The decision to invest in the technology by the contractor, however, will depend on a sufficient number of their suppliers investing in the use of this technology also. The supplier's representative was considering investing in the technology, however, similar to the contractor's representatives, they would like to see more of their supply chain adopting this technology in order to defray the set up and annual maintenance costs. The supplier's representative was convinced that the contractor's re-keying would be significantly reduced with a minimal possibility of errors between PO, delivery notes and supplier invoices. From the supplier's perspective, this will lead to significantly less queries and faster payment. The solution provided the supplier with the confidence that the 30 days credit target could easily be achieved, however, there may be some reluctance in the marketplace, in particular from contractors to becoming more efficient in their payment cycles.

The authors found that the time saving could conservatively lead to a potential saving of €10,000 per annum for the contractor. It is important to appreciate that the pilot supplier was a relative small volume supplier to contractor, in comparison to others. The contractor reported that there were 596 POs between the two companies in 2006. The more suppliers that invest in the technology and that trade with the contractor, the greater the potential savings for the contractor.

The vast majority of original objectives, identified earlier, were fully achieved. Table 1 summarises the achievements of the pilot project objectives.

It can be seen in Table 1 that all the 2006 pilot project objectives were successfully achieved.

The process of educating the industry about the benefits of eCommerce has involved a number of research methodologies since 2002. It began with the authors undertaking observation studies and studies in 2002 and again in 2006 (Hore and West, 2005a). The findings from these studies clearly demonstrated the need for current purchasing processes to be re-engineered to introduce efficiencies and to enhance the audit trails associated with the various activities that are undertaken in the supply chain. During the period 2002 to 2006, there were two studies undertaken which demonstrated that the technology necessary for implementing a electronic supply chain exists and could be deployed successfully in the construction industry (Hore and West, 2005b, 2005c,2005d and 2005e).

4 CITA E-COMMERCE GROUP

For the past two years CITA have been working on the CITA eXchange (CITAX) project which sought to verify that significant measurable economic benefits can be achieved by collaborating trading network members by the use of existing ICT standards in their business processes (DETE, 2006, West and Hore, 2007 and EC, 2007).

In 2006, CITA was successful in applying for funding from Enterprise Ireland, a state agency that is responsible for the development of indigenous Irish industry, to support a project that seeks to review and/or develop standards for the electronic exchange of information between interested parties in the construction industry. The funding has enabled CITA to create a project called CITAX (Construction IT Alliance exchange) that is organised into five modules, one of which is examining eCommerce, while the others deal with the exchange of drawings, electronic tendering, project collaboration and computer aided measurement (West and Hore, 2007). The CITAX project focused on five module areas:

– Module 1 – Production and exchange of CAD drawings.
– Module 2 – Production and exchange of trading documentation, such as purchase orders, goods received notes and invoices.
– Module 3 – The pricing of tender documentation electronically and recommendation of a preferred tender for selection.
– Module 4 – The storage, retrieval and general dissemination of project information on construction projects.
– Module 5 – The use of CAD software in the production of bills of quantities.

Each module involved a Project Leader drawn from industry together with a cross section of companies from different disciplines, including the support of an academic institution. The module 2 team focused on the following objectives:

1 Develop a universally acceptable XML standard for electronic exchange of purchase orders, delivery notes and supplier invoices.
2 Demonstrate, by participation in a live pilot project, that purchasing data transactions can be more efficiently exchanged between trading network members by the adoption of the XML standard.

The existing supply chain process has been evaluated and a cost model developed to allow individual organisations estimate how much the traditional supply chain process is costing them. The team has also developed a revised business process based on exchanging transactions electronically, and has also developed a revised cost model that allow organisations to establish the savings that they can achieve through eCommerce. A pilot project is underway to prove that the savings identified by the team in the course of its work can be achieved when the technology is implemented in practice. One of the most significant challenges for the CITAX module 2 team was how to tailor-make a suitable XML standard that would be acceptable to the vast majority of players in the Irish construction sector, especially as many traders are small enterprises. For the adoption of a common XML to be widespread, it was important that the companies participating in the project would define and agree sets of message sets for each of the stages of the trading process.

XML standards have been developed in several industries, such as business, retail and also the building and construction industry. For example, the Building and Construction XML (bcXML) (Toleman et al., 2001), Electronic Business XML (ebXML) (Lima et al., 2003) and Industry Foundation Classes XML (ifcXML) (Froese, 2003). These standards are essentially shared vocabularies and rules for defining the structure, content and meaning of similar XML documents. XML is extensible because each element of data is separately identified, all of the elements do not have to be present in the message, only the elements that are required by the message definition, the XML schema. The module team identified a number of messaging formats that needed to be agreed among the participating companies, with the intention of developing a CITAX XML Trading standard (see Table 2).

Having reviewed the standards available, the team chose to use as a base the BASDA eBuild XML standard. A variety of other standards were reviewed such as EDI and GS1 XML, but the eBuild XML standard is currently used widely in the UK construction industry, although there are a number of new messages that will have to be developed by CITA, particularly for PODs and GRNs. It has also become apparent that the proliferation of standards means that each organisation that trades electronically has to have a flexible system that caters for all of the other standards in the marketplace. The possibility of universal buy-in to one common XML schema, though difficult to achieve, has obvious advantages and is vital to successful industry-wide implementation.

The module team are currently organising the pilot or testing phase, engaging with software users and vendors. Presently there are two pilot projects underway that will adopted the eBuild XML standard. The unwillingness of some software vendors to interoperate with other software companies is a very significant hurdle that has to be overcome by the industry.

Preliminary findings from the project demonstrate that there are significant opportunities for increased efficiency and effectiveness in the industry. A strong business case has been made for ICT adoption, through:

1 Accelerating the industry adoption of CAD standards, electronic commerce, electronic tendering, electronic collaboration and computer aided measurement within the Irish construction industry.
2 Accelerating the industry adoption of product data standards sets that will support electronic

Table 2. CITAX Module 2 XML Message Formats.

Message Type	Message Content
Order	Order messages are created by the contractor and sent to the supplier.
Order Confirmation	On receipt of an order from a contractor, it is created/saved on the supplier's system. Confirmation of the details recorded/received is transmitted back to the supplier. This can include out of stock notifications. This message can also be used to create an order on the contractor's system if it has not been recorded there previously.
Order Cancellation	Used to cancel an order that had previously been sent through from the contractor.
Shipping Notice	An Electronic Shipping Notice (eSN) is an advice from the supplier to the contractor listing the items that are to be delivered. It is effectively the supplier's dispatch note and is transmitted in advance of the delivery as soon as the dispatch details have been verified by the supplier.
POD	A POD (Proof of Delivery) is a document that lists items delivered together with the contractor's signature, captured electronically. It is the basis on which contractors can be invoiced for items delivered.
GRN	A GRN (Goods Received Note) is the contractor's equivalent of the POD, i.e. it shows from a contractor's perspective what was delivered to site.
Invoice	Document that charges the contractor for items delivered.
Credit Note	Document that credits the contractor account for items such as pricing corrections; credit for items not received; or credit for damaged items.

commerce activity within the Irish construction industry.

3 Accelerating the adoption of interoperable building information model-based software through testing and demonstration.
4 Establishing methods that facilitate the harmonisation of existing building information modelling and bring consistency to the construction industry's efforts to integrate the supply chain with common information models.
5 Assisting the Irish construction industries in developing and implementing interoperability standards and work process improvements that reduce the life cycle time, costs and risks.

5 IMPLEMENTATION OF ICT COMMUNICATION STANDARDS IN IRELAND

Having demonstrated the business case for both contractors and suppliers to adopt ICT in their conversion to e-commerce practices, the key to success in implementing any ICT standards involves reaching cross-community agreement on a willingness to participate through:

1 A strong commitment from leading construction industry companies to collectively rather than individually take a lead and actively participate in the implementation.
2 Demonstration of the potential impact of ICT standards in
3 Creating a step-change in communication efficiency for all parties to the supply chain
4 Developing new or adoption of existing international standards
5 A willingness of suppliers to adopt the new XML standards for document exchange in their purchasing software and to invest in developing a supplier-specific product code database for ordering.
6 An openness of all major software vendors associated with participating contractors and suppliers to alter their software to accommodate the new XML standard. The work undertaken by the software vendors must be financed by the demonstrable efficiency gains of the contractors and suppliers on implementation of the new e-purchasing practices.

An example includes creating generic codes for products to which both suppliers and buyers would map their product codes. This would mean that buyers and suppliers would only have to map their codes once. Through the CITA eCommerce group a wide platform has been created which has facilitated dialogue between these three parties, which otherwise would not have been possible.

The methodology currently adopted by the CITA eCommerce group includes:

1 Secure contractor and supplier commitment within the Irish construction supply chain.
2 Establish a steering group to manage the direction of eCommerce implementation.
3 Agree infrastructure for messaging formats and exchange mechanisms.
4 Establish CITA project management support.
5 Initiate implementation programme with steering group members.
6 Rollout implementation across the industry.

The challenges facing the Irish construction include:

- develop tools, protocols and standards which are non-proprietary and which facilitate interaction between participants in the industry.
- define and promote standards in data communications.
- through piloting, measurement and demonstration, promote building information modelling across the industry.
- identify and design services and products which will enable the participants in the industry to work collaboratively through the supply chain in Ireland and internationally.

Despite these challenges, it is likely that the industry will begin adopting ICT standards in the short term, although it is recognised that it will take time to filter through the entire industry. The adoption of e-procurement by a sufficient threshold of parties is likely to catalyse others in the market because the use of e-procurement will be seen as a providing competitive edge, much as quality assurance schemes did in the 1990s.

6 CONCLUSION

The overall aim of the pilot project was to re-engineer the purchasing process within a contractor's organisation, by enabling an electronic three-way match of the PO, delivery docket and invoice data, thus enabling a significant improvement in both productivity and overall administration costs per transaction. In order to verify that the process has been successfully re-engineered, Li (1996) suggested that an evaluation of the results must indicate that the re-engineering goals were achieved.

The goal of achieving a paperless process was largely achieved with an acknowledgement that some paper is a necessary ingredient of any business process. A sophisticated level of integration was achieved between the ICT tools deployed in the pilot project, with an end-to-end seamless population of data between both trading partner's ICT systems. There was no incidence of mislaid documentation being reported throughout the pilot project period. There was only a limited degree of re-keying of information by the contractor's staff during the matching process, namely, in order to verify receipt of the electronic information. The ultimate goal of achieving a three-way electronic match of the PO, delivery docket and the supplier invoice was fully realised. These results show clearly that significant productivity improvements and potential savings are achievable for the wider construction industry should this re-engineered solution be deployed (Hore, West and Gunnigan, 2004).

A measure of the success of the current project can be seen in the response of the industry to the work that has been undertaken to-date. Even before the project has completed its work, 11 major Irish contractors have expressed an interested in investigating the implementation of eCommerce into their own organisations. They have asked for expressions of interest from their suppliers in working with them on this and this approach has been met positively by the initial set of approximately 25 supplier companies that have been asked to participate. The expected results include the setting up of a dedicated eCommerce group by CITA to provide independent advice and support to the members that are embarking on implementing eCommerce. An additional expected results will be the implementation of a standard data pool to facilitate the interoperable exchange of product codes between trading partners which is presently ongoing.

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Workshop: CoSpaces

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Mobile maintenance workspaces: Solving unforeseen events on construction sites more efficiently

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ABSTRACT: This paper presents the process of solving unforeseen events on construction sites – a frequent phenomenon throughout the industry. The current process of handling an unforeseen problem is described and contrasted with a future scenario in which I&C technologies are applied to solve unforeseen problems on large construction sites more efficiently: augmented reality, positioning technology, knowledge support and involvement of remote experts. The Mobile Maintenance Workspace, a range of applications to support mobile workers in their maintenance work, and its underlying software framework is outlined. The work presented here is currently being carried out in the European Integrated Project *CoSpaces*.

1 MOTIVATION

The construction industry is faced with a dilemma that until, and even while, building is in progress some problems are not foreseen and this has impact on the handover time to the customer. This invariably implies default and penalty clauses that affect the profitability and the ROI (return of investment) for the builder. As building realization necessarily uses local labour, plans and construction information are not always interpreted correctly in line with the design intent and the architect's vision.

These frequent unforeseen situations require a decision or action urgently. Such decisions often require a chain of authorization involving a diversity of actors. These situations may fall outside the responsibility of the operative on site, though he/she might, nonetheless, initiate a decision or knowledge acquisition process that is likely to engage these actors and other experts. All these events could be categorised under the umbrella of 'unforeseen events' on site, which could take various forms such as health & safety concerns and constructability difficulties. In such situations, there is a need for extensive collaboration between various actors as well as the need for external expertise which could take the form of human expertise or be present in the form of information or knowledge by accessing the relevant sources. However, the fragmented nature of construction projects inhibits orchestrated and fast decision making. Furthermore, the site-based constraints do not allow seamless access nor access across organizational boundaries to the knowledge that is required to support the collaboration and decision making processes. Given the fragmentation, the number of actors and the nature of their business, it is difficult but imperative that problems are addressed and resolved as early as possible. The adverse effect of disruptions is likely to escalate the problem by disrupting the flow of progress with a potential domino effect on the remaining construction activities. This is likely to extend the duration of the construction project and the rescheduling of the programme may result in one or more contributors not being available thus creating further disorder. When considered in conjunction with the potential legal implications of these interruptions the adverse impact could be detrimental to the overall success of the construction project.

In view of the above, it is envisaged that an improvement in the communication and collaboration processes is likely to have considerable impact on the success of the construction project which is measured in terms of project total cost, duration and quality. The introduction of collaboration technology may result in the reengineering of the problem solving process, this then leading to a further increase in productivity.

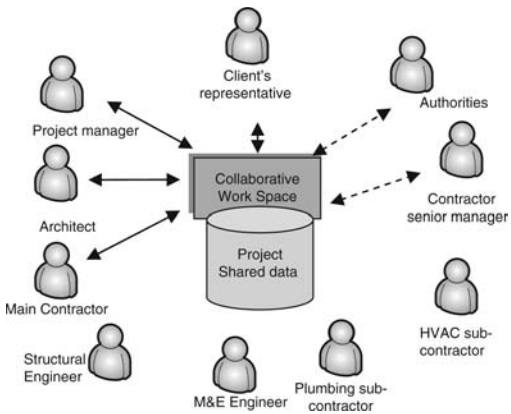

Figure 1. Stakeholders of the unforeseen problem scenario.

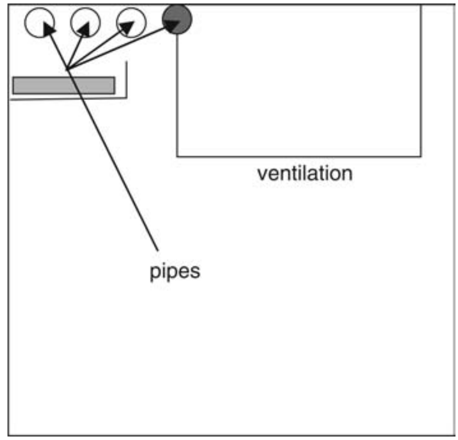

Figure 2. Clash between the pipe and the ventilation system.

2 UNFORESEEN EVENTS AT CONSTRUCTIONS SITES

This mobile scenario considers the situation facing a small or medium enterprise (SME) who is attempting to install piping services to a previously installed HVAC (heating and ventilation air conditioning) system by another SME. The problem created is that there is insufficient space and access to install the supply pipe as the prescribed space in the working order is already taken by apparently wrongly placed installations.

Both SMEs are working for a main contractor, who is carrying the overall responsibility for site operations. The stakeholders for this class of general scenario (unforeseen problems) are presented in Figure 1.

The scenario is a derivative of a more generic case associated with the occurrence of 'Unforeseen Events', where there is a need for information and decision-making from a variety of stakeholders to resolve the problem as early and efficiently as possible. An unforeseen event could relate to risk matters, hazard and emergency issues. It could take various forms and shapes, such as unforeseen design faults, or issues pertaining to buildability (or constructability), site logistics, health & safety, hazard spotting. Several objectives could be speculated as being associated with this scenario. These could vary from legal to promotional and professional imperatives. A range of generic objectives include: cost minimization/profit maximization, following rules, aiming to attain glory, quality assurance and rules and regulation compliance, risk evasion/management, problem ownership, impact assessment and performance competency measures (e.g., key performance indicators).

In all situations the main objective is to reach a resolution in the most efficient way and in the minimum of time, without excessive cost implications. This is to be achieved through better means of communication in an efficient collaborative setting. This includes better and faster communication of information and decisions.

2.1 *The scenario: An unforeseen problem at a construction site*

After the installation of the plumbing and ventilation system in a basement, the SME1 operator arrives on site to install a pipe but realizes there is a pipe collision problem (Fig. 2). There is not enough space left by the existing pipe installations and he can not install the pipe as the wrongly accepted ventilation shaft has been mounted before. The shaft is 5 cm wider than described in the project and in the specification to the supplier. The existing pipe installations supply H/C water and steam. Under the pipe installation the electricians have already mounted the cable trays for cables and their work is halfway to completion.

The stakeholders involved in the scenario are represented in the following table:

The SME1 operator communicates with his/her SME1 foreman to report the problem. The SME1 foreman tries to get in touch with the site project manager. If he/she is on site, he will investigate the problem, if not, the SME1 foreman has to wait, which might take up to half a day. When the SME1 operator finds the project manager, they try to see if the pipe can be placed in another position. After checking the drawings, however, the project manager and SME1 find that this is not possible and that the ventilation shaft takes up too much space in contradiction to the design. At this stage, the job is falling behind as a change has happened and so there is a need to raise a request for a design change.

Table 1. Stakeholders in the construction scenario.

Stakeholder	Role
Project Manager (PM)	represents the Main Contractor – based on site
Client's Representative	represents the client, controls quality, cost and time on site
Architect	produces the architectural design and drawings
Structural Engineer (SE)	produces the structural design and drawings
M&E Engineer	produces the Mechanical Engineering design and drawings
Plumbing Sub-Contractor (SME1 foreman)	plumbing work – based in the office
SME1 operator	in charge of installing plumbing work on site
HVAC sub-contractor (SME2 foreman)	heating, ventilation and air conditioning work – based in the office
SME2 operator	in charge of installing HVAC work on site
Quantity Surveyor	responsible for estimates
Contractor Senior Manager (CSM)	being reported to by PM – based in the company
Commercial Director	evaluates cost implications
Authorities	e.g.: fire, environment, police, planning, etc.

The project manager now communicates with the SME2 foreman to brief him about the problem. One of the problems identified here in the construction industry is that the Main Contractor (or the project manager) talks one language, and the SMEs (sub-contractors) each talk different languages due to domain terminology. This sometimes results in confusion, hence cost increases and time delays that might partially be solved by sharing more visual than textual information.

The project manager, the SME1 foreman and SME2 foreman will try to speculate on the source of the problem. After further checking, the problem seems to be design related. So far no solution has been determined.

The project manager at this point consults his design team to identify whose fault it is. The M&E engineer who did the specifications will try to find someone to pass the blame on to (blame culture). If it is an error in design, he will try to correct it and give solution to the project manager. If it is not a design problem, then he will try to see if it is an implementation or control problem. The project manager liaises with the appropriate consultant(s) from the design team to get clarification of the problem and come up with a solution. A site meeting then needs to be organized. So the project management decides to have a face to face meeting on site with the design team to review and discuss the problem and to look at the various solutions

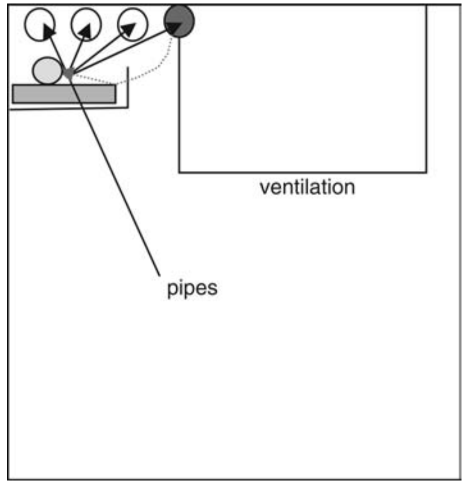

Figure 3. Solution of pipe clash.

in cooperation with the SME1, SME2, and the design team.

The project manager, the two SME foremen and the design team all have a meeting on site. After studying the drawings, they agree it is a supply fault of the supplier and partly of the SME2, as they did not report that the shaft was in a size other than prescribed. There is now a delay of several weeks on site, while the project manager communicates with the contractor senior manager and reports to him to get authority to suggest alternative solutions, as well as confirmation that he is heading in the right direction. He is also communicating with his commercial director for any cost implication or contractual issues.

Next, the client representative organizes a meeting between the M&E engineer and the structural engineer to accommodate the extra pipe and also to decide the change specification. The project manager asks his quantity surveyor for a cost estimate for the work.

Then the client representative communicates with all the relevant consultants from the design team such as the engineers, the SME1 foreman and the SME2 foreman as well as all the regulatory authorities (such as fire, building control, environment, police and planning) to provide an approved solution taking practicalities into account.

To replace the ventilation shaft with a new one matching the prescribed size would be far too expensive. The electrical installation cannot be moved and the only solution is to mount the natural gas under the cold water pipe using a special suspension that needs approval from the authorities before final acceptance of the solution.

The newly approved variation specification that was done by the engineers will now be sent to the SMEs for

Table 2. The process of solving unforeseen problems – current practices.

	Actor	Action(s)	Result(s)
1	SME1 operator	identifies problem	problem: pipe collision
2	SME1 operator → SME1 foreman	reports problem	report (oral)
3	SME1 foreman → PM	reports problem; consults drawing, tries to find quick solution	no success
4	PM → SME2 foreman	briefs	
5	PM + SME1 foreman + SME2 foreman	speculates on source of problem	seems to be supply related problem
6	PM → SME1/SME2 foremen+engineers	site meeting: confirms source of problem	confirms supply related problem by deliverance of wrong ventilation system: lack of space, various proposals for solution
7	PM → Contractor Senior Manager + Commercial Director	informs for authorization to initiate solution process; consider costs, legal, procedural implications	authorization & confirmation of course of action
8	M&E Engineer → architect	instruction to accommodate pipe	revised design
9	PM → Quantity Surveyor	asks for cost estimates	cost estimates
10	PM → M&E engineer + architect: site meeting (consultants: structural, electrical) + SME1 foreman + SME2 foreman + regulatory authorities (fire, building control, environment, police, planning)	site meeting with consultants (structural, electrical): discuss solution and consider practicability issues	agreement on solution
11	SMEs	verify cost implications	cost estimates, revised
12	PM → Contractor Senior Manager	asks for final authorization	final authorization
13	PM → SME1 foreman	provides new specification; signs variation document	variation document, authorized by signature
14	SME1 foreman → SME1 operator	translates specification; returns to work on site	solution is being implemented

costing variation. The project manager then contacts the contractor senior manager to get a final authorization to go ahead with the work and install the pipe. By order from the client's representative, the project manager communicates with the SME1 foreman and provides him with new specification and signs the variation document.

2.2 *Process*

The process as describe above can be summarized as follows:

2.3 *Current use of technology*

The following (non-exhaustive) list of material and communication technology which is currently in use on construction sites and in the back-office was put together from interviews with several construction companies:

- drawings on paper
- specifications on paper
- 2D CAD drawings
- photographs
- inspection sheets and non-conformance reports for site supervisor
- time sheets for all resources (human and non-human) and processes
- cost management, e.g., spreadsheets
- project management tools in back-office
- progress information forms
- RFI form (request for information) for site engineer to capture information of problem

– diary information for site engineers
– briefing acknowledgements by foreman
– check-lists, e.g., for health & safety
– written or spoken reports including photographs and sketches
– oral training records for operatives
– photographs of site problems sent to consultant, record of oral conversation with consultant
– notifications of revisions of drawings and specifications on paper
– communication media: (mobile) phone, face-to-face meetings, e.g., on site, email, paper, fax.

3 FUTURE SCENARIO

3.1 *Future process*

The future scenario proposed here is based on the current scenario described above. It illustrates the effective use of technology in replacing the need for some of the remote meetings. Its objective is to make the meetings more effective with better common understanding between the participants, to consider more views and for decisions to be reached much faster. As indicated earlier in the current scenario, one of the challenges in the construction industry is to improve communication which currently necessitates several joint meetings, many of them on site. While it might not be possible to force a common language onto the inhomogeneous team, the increased use of visual information, such as pictures, photographs, drawings, video etc. might prove useful in helping the project team share the same views and in providing them with a common and better understanding of the problem. In order to achieve this, information needs to be available and shared much faster between members of the project team independent of their location in an easy way to be understood by those who need it. As a consequence, fewer meetings are required due to communication problems and decisions can be made faster. This will accelerate building in the construction industry and make the collaborators more available for fast responses when their expertise is required for minor issues.

In order to render decision-making more effective and efficient, there is a need for a decision support system which will provide the stakeholders with suggestions of alternative solutions: a knowledge repository holding the history of problems identified in the past and how they had been solved. This helps the stakeholders not to "re-invent the wheel", but rather to rely on previous solutions, if possible. The problems are classified according to a predefined set of keywords that are relevant to categorize such information. Stakeholders browse the knowledge repository for relevant solutions, based e.g. on similarity patterns.

When the SME1 operator visually identifies the problem concerning the pipe collision as he arrives on site and realizes that the model he has does not correspond with the current situation, he uses his mobile device to take a picture and directly sends it to his foreman to report the problem. There is also an ICT station installed on site which is managed by the Project Manager for communication of large data and in case the mobile communication infrastructure is insufficient. The new technology here offers an opportunity for the SME1 operator to officially communicate to his foreman (who could be located in another site or in the office) and gives the latter an informative picture about the problem by sending digital imagery electronically to the SME and using video conferencing for communicating the problem.

The SME1 foreman needs to communicate the problem to the Project Manager. Since the PM is usually hard to reach, the foreman uses his mobile device to access the system and find out whether the PM is available and how to contact him. In fact, the PM is at his office and can be reached at his PC. PM realizes that this situation indeed presents a problem and sets up a shared virtual workspace. From previous similar problems he finds out who the stakeholders are and invites them to a virtual workspace.

In the communication between the stakeholders, mobile technology plays a crucial part to communicate and exchange information such as video conferencing and the use of digital images. The use of 3D models will assist both the Project Manager and the SME1 foreman to try to find quick solutions for the problem. Fewer face-to-face meetings are required as each will have access to mobile technology.

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RFID technology is used for tagging physical objects at the construction sites, e.g. rooms, pipes, ventilation systems. Thereby the objects can be uniquely identified and related to their contextual data in the back-office. The RFID tag attached to the pipe which is in conflict with ventilation system holds meta data on the pipe's identification and specification. The SME1 foreman uses an RFID antenna to read the tag and then downloads (either to his mobile device or to the ICT station on-site) all relevant material related to that pipe which is stored in the back-office database. This includes drawings, specifications, check-lists, (non) conformance reports, action history, etc. Recording of actions back to the back-office system provides a decisional context which can be useful to trace back all decisions and actions that took place e.g. re-engineering, or litigation.

The Project Manager then briefs the SME2 foreman about the problem using similar technology as discussed in the previous stage. As before, the availability and contact database is used to find the best way to reach the foreman.

At this point, another virtual meeting takes place as both SMEs, the Project Manager and the architect speculate about the source of problem (each one of them are in different locations). Augmented reality technology is utilized to impose a virtual 3D model on the real setting: alternative solutions can thus be made visible to the engineers on-site and various options can be discussed – visual information helps reduce the impacts of different "languages" and increases the common understanding between the different cultures in the construction industry.

As the engineers realize that the problem is supply related, they normally would need a site meeting with all members of the design team. By using CoSpaces collaboration technology, however, a site meeting is no longer required and the various members of the design team, together with the Project Manager and the SMEs, will communicate efficiently as if they were all based in the same location by using tele-immersive technology.

As the virtual team meeting results in confirming that the problem is due to lack of space caused by the supplier, the Project Manager communicates with his Contractor Senior Manager for authorization to initiate the solution process. Minutes taken here are contextualized to allow for later reference to them, as are digital images, acquired on site. Communication takes place via an audio/video conference. The same technology can also be used by the PM to discuss the cost implications with his Commercial Director. All relevant outcomes of the various meetings are stored back to the system and thus are available for tracking and for future decision support.

The engineers, often based at different locations, use simulation tools and 3D models to accommodate the pipe and relocate it. Revised models and drawings are checked back into the system by each of them. The system keeps track of the change history and takes over version management. Meanwhile at the Quantity Surveyor's premises, cost estimation is done using the tools they are familiar with and cost estimation documents are also checked back into the system and – like all other relevant material, history data and meeting data – become part of the pipe's contextual data which can be easily found and retrieved at any time using the RFID tag.

Another virtual meeting takes place involving the PM, SMEs and all members of the design team and minutes and decision reports are taken and stored in context. Minutes, decisions, actions and check-lists and other meeting data are saved and become part of the problem's context. Virtual meetings help reduce the number of face-to-face on-site meetings which results in considerable savings for the project in terms of time and cost as it normally takes days to organize such a meeting to satisfy all the stakeholders.

Having completed the design change documentation about relocating the pipe, the document is made available electronically to the SMEs for timing, resource and costing procedures.

It is worth mentioning that most of the data is exchanged across organizational boundaries and some of it is security relevant. If necessary, confidential data like cost estimates and authorization documents can be securely transferred and the data itself is secured by using encryption technology and authorized using electronic signatures.

The PM communicates with his Contractor Senior Manager by using electronic contracting to issue the final authorization. The PM will then provide the new specification to the SME1 (management, foreman and operator) using an audio/video conference and 3D models. The use of augmented reality will help in instructing the operative to perform their tasks according to the new specifications. The document is then verified by signing it electronically. The operator returns to site to actually relocate the pipe.

3.2 *Current and future practices: Added values*

While the nature of the scenario implies that the process of solving the problem will not essentially change in the future, the means to do so has the potential to considerably change in future. Table 3 enhances the description of the current problem solving process, as depicted in table 2, by applying possiblefuture practices.

4 COSPACES SOFTWARE FRAMEWORK AND MOBILE MAINTENANCE WORKSPACE

The overall objective of the CoSpaces project is to develop organizational models and distributed technologies that support innovative collaborative workspaces for individuals and project teams within distributed virtual manufacturing enterprises. We

Table 3. The process of solving unforeseen problems – future practices.

	Actor(s)	Action(s)	Current practice	Future practice
1	SME1 operator	identifies problem	visually	Visually observed, with digital photo and audio/video assistance.
2	SME1 operator → SME1 foreman	reports problem	physical, mobile phone, oral report	mobile device with camera, video conferencing, RFID technology for identification and contextualization of problem issue. ICT station on-site for full communication facilities
3	SME1 foreman → PM	reports problem; consults drawing, tries to find quick solution	physical, mobile phone, paper drawing	mobile devices with digital imagery and audio/video conferencing, 3D models on stationary PC, VRML models on mobile devices, location tracking of persons, tracking of resources (RFID) to identify relevant drawings on database, check availability and contact data of PM, database of recent similar cases, set up virtual shared workspace with stakeholders
4	PM → SME2 foreman	briefs	phone, mobile phone, email	mobile devices with digital imagery and audio/video conferencing
5	PM + SME1 foreman + SME2 foreman	speculate about source of problem	phone, email, physical meeting, paper drawings, pictures, physical inspection	various options using AR technology on-site are discussed, various 3D models to investigate options, database of recent similar cases
6	PM → SME1/ SME2 foremen+ engineers	site meeting: confirm source of problem	email, meeting, phone, post, fax, drawings, picture, visual inspection	various options using AR technology on-site are discussed, various 3D models to investigate options
7	PM → Contractor Senior Manager + Commercial Director	informs for authorization to initiate solution process; consider costs, legal, procedural implications	physical meeting, phone, email, inhouse system, drawing, pictures	audio/video conferencing, digital imagery, meeting material (minutes, check-lists, decisions . . .) , context provision
8	M&E Engineer → architect	instruction to accommodate pipe	drawing, 3D model	3D model, potentially simulation and structural analysis
9	PM → Quantity Surveyor	asks for cost estimates	cost estimation using in-house system	cost estimates are linked to problem context
10	PM → M&E engineer + architect: site meeting (consultants: structural, electrical) + SME1 foreman + SME2 foreman + regulatory authorities (fire, building control, environment, police, planning)	site meeting with consultants (structural, electrical): discuss architectural design solution and consider practicability issues	physical meeting, phone, email, drawings, pictures	mobile collaboration, augmented reality to try out various options on-site, electronic drawings and pictures

(continued)

Table 3. *(continued)*

	Actor(s)	Action(s)	Current practice	Future practice
11	SMEs	verify cost implications	manual verification	electronic access to relevant contextual data
12	PM → Contractor Senior Manager	asks for final authorization	post, email, fax, drawings, contractual information on paper	electronic access to relevant contextual data, authorization document is securely transferred and electronically signed
13	PM → SME1 foreman	provides new specification; signs variation document	phone, physical meeting, fax, post, drawings, contract on paper, textual instructions	audio/video conferencing, augmented reality for visualization, 3D model, RFID technology for identification of resources
14	SME1 foreman → SME1 operator	translates specification; returns to work on site	phone, physical meeting, drawings, textual instructions	as above

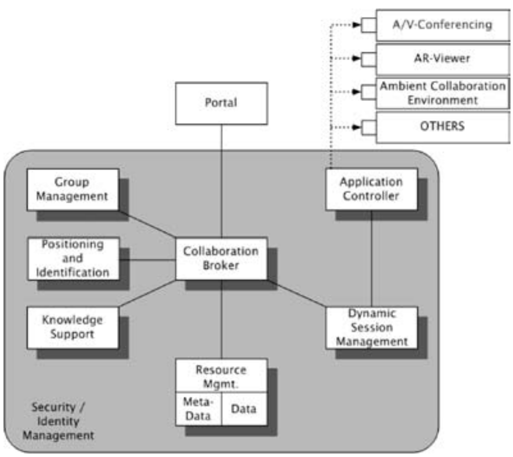

Figure 4. Functional view of the main building blocks of the software framework.

explore how advanced technologies such as virtual reality, augmented reality, tele-immersive interfaces, mobile technologies, context-awareness and web services can be deployed in creating human-centric collaborative workspaces for supporting product design and down stream maintenance and constructability processes. The CoSpaces project aims to create an underlying configurable and dynamic software framework so that the system can easily be adapted to suit the user and his/her context (Fernando & Hansen 2007).

The distributed software framework is validated by three kinds of collaborative working styles required for collaborative design and engineering in three sectors: aerospace, automotive and construction. Three generic classes of collaboration workspaces – *distributed design workspace*, *co-located workspace* and *mobile workspace* – are used to validate the distributed software framework. It is the latter workspace, the Mobile Maintenance Workspace, which is particularly targeted towards the construction industry.

CoSpaces workspaces make use of the services of the CoSpaces software framework. Its main components are depicted in Figure 4.

Apart from basic services such as Security and Identity Management the Mobile Service Workspace mainly makes use of the following framework components from basic services:

- Portal, the main HTML based user interface entry
- Collaboration Broker, brokering the CoSpaces framework components and serving the Portal
- Group Management service
- Knowledge Support service
- Mobile Augmented Reality framework

4.1 *Mobile access to CoSpaces' services*

For access to general CoSpaces' services at the user interface, we use the Web-based Portal user interface in order to present the end-users with a consistent user interface throughout the various CoSpaces workspace types. While using the Portal as global entry point for accessing CoSpaces services is realistic for laptop devices and state-of-the-art ultra mobile PCs, this is not always the case for other mobile devices such as PDAs. For these devices, specifically designed light-weight mobile applications are provided.

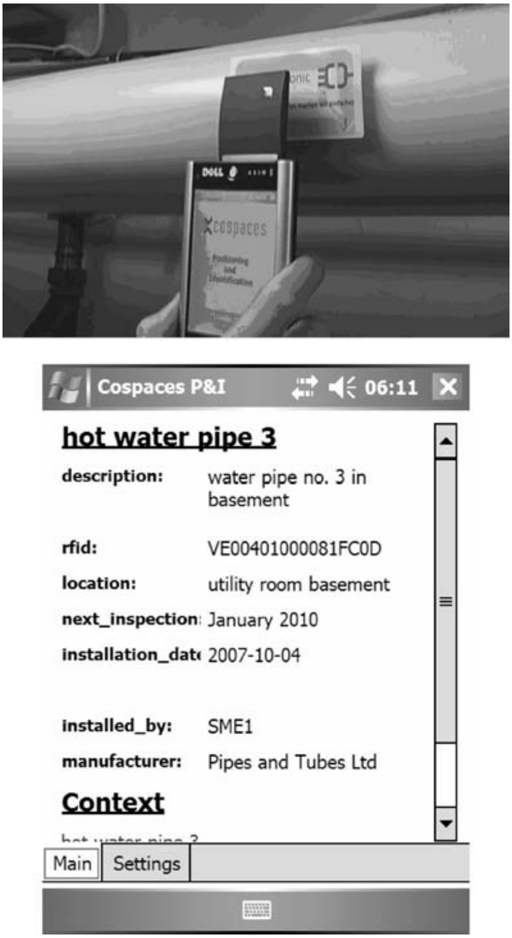

Figure 5. Positioning & Identification Viewer – user interface.

Figure 6. Augmented Reality viewer – desktop and mobile user interfaces.

4.2 *Light-weight mobile applications*

For reasons of limited data transfer bandwidth, limited screen size, or limited browser capabilities, both functionality and user interface on mobile devices have to be restricted and adapted to the devices' capabilities. The Mobile Service Workspace concentrates on supporting asynchronous access to the CoSpaces services. Depending on the mobile device capabilities, light-weight mobile applications are provided in addition to the standard Portal access point. The following special mobile applications with a restricted set of functionalities are currently being implemented (apart from the AR Viewer application mentioned in section 4.3):

– *Positioning & Identification Viewer*
  Identify a person or resource using tracking technology like RFID or WiFi and provide contextualized information about him/her or it.
– *Knowledge Viewer*
  Provide access to a basic set of information stored in the Knowledge Support component and present it in a suitable form on mobile devices.
– *People Finder*
  Browse the personal address book and look for people and their profiles, e.g. when looking for an expert to consult on a problem.
– *Presence & Availability Viewer*
  Find out who is online and available for being contacted.

4.3 *Augmented Reality on mobile devices*

For Augmented Reality applications on mobile devices, we provide a mobile AR software framework. Based on the AR framework *Morgan* (Ohlenburg et al. 2004), it is particularly suited for the limited capabilities of mobile devices and to their platforms.

A short demonstration video describing the future scenario of solving unforeseen problems by means of tracking technology and Augmented Reality technology is available for download (Fraunhofer FIT 2008).

5 OUTLOOK

The Mobile Maintenance Workspace is currently being tested and evaluated in *Active Distributed Development Spaces* by the CoSpaces consortium and in a later phase in a Living Lab at construction sites in the Netherlands and in Denmark. Results from the evaluation are iteratively being fed back into the development process. The CoSpaces project will end in 2009.

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Futuristic design review in the construction industry

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ABSTRACT: Many researchers have already demonstrated the benefits of enhancing collaboration in the construction industry and the role of IT as a facilitator of inter-enterprise communications is also well accepted. However, construction companies are slow to implement these best practices because they do not address the real needs of workers. This paper goes further than previous approaches by describing not only the technological requirements that permit cooperation in a construction project, but also the human factors that need to be addressed in order to achieve effective collaboration. These requirements are illustrated by a futuristic scenario which shows how state-of-the-art human-centric technologies could support the interactions of co-workers during a design review meeting. This scenario will be used as a demonstrator of the CoSpaces platform for collaboration, and some of the technologies developed for its implementation will be introduced here.

1 INTRODUCTION

Collaboration is a process that aims at achieving "shared thinking, shared planning and shared creation" (Montiel-Overall 2005). This implies that the stakeholders have a common understanding of the project which permits them to reach consensuses when taking decisions (Gautier et al. 2008). Collaboration as defined here is particularly challenging to implement in the construction industry, where projects often involve a large number of stakeholders representing a diversity of disciplines and skills (Lu & Sexton 2006). In addition, local SMEs are usually employed for specific tasks within the project, so that total quality management becomes impossible to implement. Even if several studies have demonstrated that efficient collaboration could greatly improve construction projects, the complexity of its implementation slows down its integration in the industry (Benchmark research 2005).

The scenario presented here aims at expressing a realistic vision of the industry concerning the way in which advanced technologies could support collaboration in construction projects. The scenario focuses on a co-located meeting during the design phase of a project and it presents some pervasive and user-centric technologies that could facilitate the integration of collaboration in these projects. The choice of this phase is due to the large number of stakeholders involved in its validation, as well as to the potentially high repercussion on price or time if a poor design leads to rectification actions at a later phase. Therefore, this is one of the phases where efficient, technology-supported collaboration can have a greater impact.

This paper starts with an analysis of current collaborative practices in the construction industry. It takes both the social and organisational aspects of projects into consideration before a futuristic co-located design scenario is presented. This scenario illustrates the vision of the CoSpaces project concerning how the technologies could enhance collaboration in the construction industry in the future. Then, the technologies required for its implementation are discussed as well as the way in which they need to be combined in order to offer an adequate working environment to the user.

2 CURRENT ISSUES

The main purpose of any collaboration is to share viewpoints in order to take decisions to solve unplanned events or to foresee later issues. The construction industry tackles these decisions in two different ways (Gautier et al. 2008). Firstly, periodic meetings can be organised during the whole of the product life cycle as part of the project management. These so-called decisional gates have the objective of ensuring that issues or potential issues are identified across and between the various competencies/skills that are involved, so that an optimised way forward can be agreed. Indeed, many studies have shown that identification of problems early in the life cycle can avoid excessive exponential cost and time overruns (Bassanino et al. 2001, Blyth & Worthington 2001). Secondly, unplanned meetings might be necessary to address urgent issues. These reactionary meetings are more likely to happen at a later stage of the project when a rapid decision is required to avoid incurring delay. In addition, this decision often has to take into consideration the work of other stakeholders in order to avoid prolongation of the problem.

Reactionary (unplanned) meetings can be partially avoided by improving the efficiency of the decisional gates. To do so, the number of stakeholders' viewpoints considered during these meetings should be maximised, and the system should support both formal and informal inter-disciplinary communications. Social relationships are mainly important during the initial phase of a project as they enable the participants to share a common understanding by enhancing in-depth discussions. Indeed, it has been demonstrated that the efficiency of knowledge acquisition depends on previous experience (Anderson 1977). Co-workers must, therefore, understand each others' backgrounds before being able to build a shared understanding of a problem or a project.

A frequent issue of collaborative meetings is that decisions have to be postponed to the next meeting due to information not being readily available to the meeting representative of the particular competence. The stakeholders, therefore, have to wait for retrieval of further information until the next meeting. Due to the limited availability of these stakeholders, this can result in significant delays or in the reduction of decisional quality from missing viewpoints. If information and functional questions could be asked and answers delivered during the meeting decisions could be made more efficiently and speedily, with a fuller understanding of the context of the discussion. The technology can be a way to link the meeting attendants to their remote colleagues, therefore addressing these issues.

In addition, the traditional nature of the construction industry is extremely 'document-centric' with project information being captured predominately in documents. Although project information may be produced in an electronic form, in essence it is distributed among the various multi-disciplinary teams involved in the project as documents. The document-centric nature of the industry and the insufficient integration and interoperability between software applications has resulted in significant barriers to communication between the various stakeholders, which, in turn, affects the efficiency and performance of the industry. Gallaher et al. (2004) indicated that $15.8 billion was lost annually in the U.S. Capital Facilities Industry due to the lack of interoperability.

It is clear, therefore, that the construction industry could greatly benefit from increased collaborative practices. The above examples also show the need for technology-intensive workspaces in order to address issues such as interoperability, availability and reactivity. In addition, communication between co-workers from several disciplines could be enhanced by human-centric technologies such as the ones described in the following scenario.

3 FUTURISTIC DESIGN REVIEW SCENARIO

The realistic futuristic scenario hereafter illustrates the use of new technologies to improve co-located meetings by considering the above issues and requirements. The expected benefits of such a scenario is that fewer meetings are needed due to incomplete agreements, fewer problems have to be solved and it is possible to redesign as well as test alternative solutions during the meeting. This accelerates the overall project and increases the collaborators' availability in case their expertise is required for minor issues.

3.1 *Presentation of the scenario*

The scenario starts when a space that was originally designed to be a bathroom for disabled people is reduced in floor area. This is due to the addition of a separate installation shaft for a supply and ventilation system in that space in order to respond to new requirements for fire protection and safety. As a consequence, the toilet has to be redesigned, but must include similar elements as previously planned: a close-coupled WC, a basin, a bath tub, a wall hung cupboard and a window (Figure 1).

The stakeholders are identified and invited to attend a meeting at the architectural company where the new proposed design must be presented and validated by a range of people with very different perspectives, interests and concerns. The identified stakeholders are presented in Figure 2.

3.2 *The preparation of the meeting*

Gary is the project manager for the construction of a building that includes a few apartments for disabled people. In order to solve the issue presented above, he connects to the CoSpaces website, which provides some tools to quickly set up collaborative meetings. This website has been used during the overall project to organise meetings, so that all the stakeholders are already known by the system, and they all have a username and password. The website also contains information about the Virtual Organisation such as a shared calendar or a description of the roles and profiles of the stakeholders.

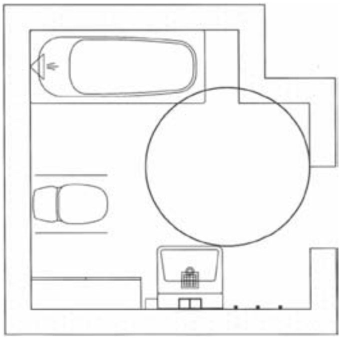

Figure 1. Possible setting for the bathroom's elements.

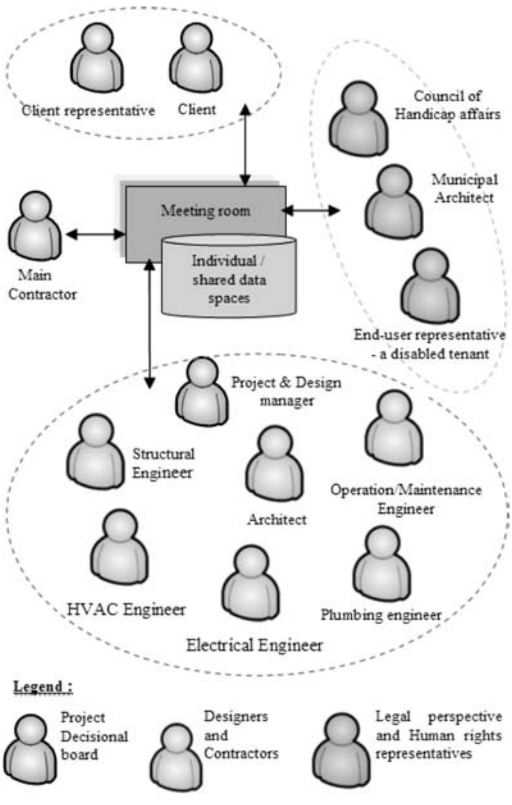

Figure 2. The meeting participants.

Gary accesses information about the stakeholders and their availability in order to facilitate the organisation of the meeting. He selects the participants as well as few dates when everyone seems to be available. When it is done the system sends an email to all the collaborators and asks for a confirmation of attendance. Gary can carry on with other work and wait for the answers.

Simon is a municipal architect who has been involved in the project since its start. He realises that he already has other appointments on the dates that he did not indicate on the shared calendar. He then decides to send one of his colleagues, Trevor, to represent him during the meeting. Trevor has been previously involved in the project, and his profile is already known by the CoSpaces website. In addition, Simon contacts a disabled person called Wayne, so that he can test the design during the meeting and share his experience with the other participants. His profile is added to the website, as well as some description of his disability, so that the interface can be adapted to his needs. Finally, Simon replaces himself by Trevor in the participants' list and he adds Wayne and a description of his role during the meeting. When he confirms their participation, a distribution list is automatically updated to facilitate later communications.

The same day, all the stakeholders have confirmed their availability and Gary is able to finalise the date. Simultaneously, the CoSpaces website creates a shared workspace automatically, so that participants can start sharing information and documents about the meeting. Part of this information forms the context of the meeting, such as the date, time, venue, objectives, participants and links with previous meetings. All these can be used to classify the meeting and allow for later references. They also allow the description of the context of the decision in order to better understand the outcome of the meeting.

Following the confirmation of the meeting, Gary produces a draft agenda and sends it through the shared workspace which distributes it automatically. A room is also booked according to the number of participants and to the required technologies. This booking can be adjusted to match new requests from the participants.

Alex is the architect of the project. Like all the participants, he receives an email with a link to the shared workspace. There, he can add documents that will be of interest to the meeting. Some of the documents he selects are available in the project data space, like the 3D model of the toilet. By default, these documents come with similar access rights during the meeting as they have during the rest of the project. In addition, the context-aware feature of the collaborative system indicates that he has recently taken part in a very similar meeting during another project. He decides to select a 3D model of that project, but restricts the access rights to his own use only, so that he will be able to use his past experience during the meeting.

3.3 *The meeting*

On the day of the meeting, the participants are given RFID (Radio-Frequency Identification) tags to track their position around the table. The user interfaces are then adapted to their profiles and roles during

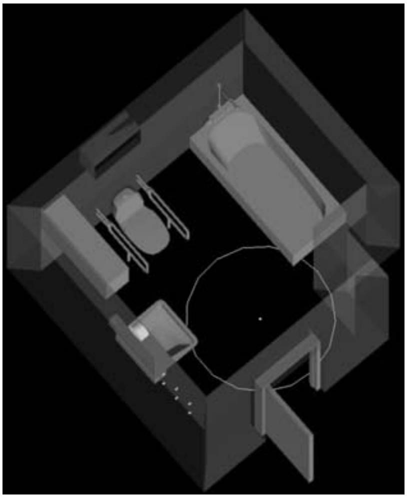

Figure 3. 3D representation of the bathroom.

the meeting. In addition, access to different tools and resources can be verified and granted without the need for multiple identification registration. The participants can also use their own devices to communicate with the system, so that they can share more documents during the meeting if required. In addition, several devices can be combined to interact with the shared workspace. For example, Alex is the chair of the meeting and he has the responsibility to manage the room facilities. He has, therefore, decided to use his mobile phone as a remote control to interact with these devices and to grant access to the shared display.

The meeting starts with a presentation of the problem and some suggested design solutions from Gary, the project manager. During the presentation, Alex annotates the 3D representation of the bathroom (Figure 3). The annotations include information on construction specifications, selected materials, colours, surfaces, installations and other relevant details.

After the presentation, each participant studies the designs proposed by the architect in a private workspace. This workspace is only accessible to them, and any document available in the shared workspace can be fully or partially copied in their private workspaces to safely explore alternative solutions. Each participant can then annotate their copies of the documents, or transform them without affecting the work of the other stakeholders. When they have finished working on their copies of the documents, they can either share them in a shared workspace or display them on a shared display. Each piece of information added in the shared workspace is then associated with the IFC (Industry Foundation Classes) model of the building.

All the participants are linked together through their computerised devices, so that they can organise themselves in small groups to discuss particular issues before sharing results with all the participants. These groups can be formed according to the roles of the participants or to resolve possible clashes with other people's work.

After this independent and group work, ideas are presented to the other participants. Alex modifies the design under the supervision of all the collaborators in line with the agreements made via discussion. These modifications are stored in the shared data space.

Wayne has been invited to the meeting to test the accessibility of the bathroom within a real-size virtual representation of the space. Once the design has been modified by the architect, he starts interacting with a model in a virtual environment. He finds that the operation space is too confined for a wheelchair and a carer and that the window cannot be reached. Therefore, all the meeting attendants work together towards a new solution.

Alex starts by changing the door width to a standard wet room door available on the market and without a step. This is achieved by linking the CoSpaces tools to some providers' database, which also provide the CAD model, cost and availability of the products. The structural engineer accepts this change from the structural point of view which he sees as causing no problems, but the electrical engineer suggests that the door opening is extended to the right as it will prevent the need to move the electrical installations.

Concerning the window, Alex stretches it to another format so that the handle can be reached. A window is available as a standard format, but the structural engineer finds that it would compromise the structural integrity of the building. Immediately after the changes have been made, Wayne tests and validates the new design.

Even though the design seems to be adapted to the client requirements, Wayne and the representative from the Council of Handicap Affairs suggest changing the bath tub to a shower. Indeed, the change will give more space and allow personal assistance if needed. The architect starts to search for specifications of pre-fabricated shower cabins with a low entry step.

In order to validate the modification against the build status, the project manager then looks at the time schedule in the CoSpaces website. He finds that the pre-cast concrete slabs as well as the walls are already completed at the factory and ready for installation. They also include conduits for all electrical installations and pipes for water, drain and sewage.

The engineers check for issues in their disciplines' layers in the model. The changes cause no problems with respect to the building structure, but the electrical engineer has to move the alarm switch to a new position. He also considers structural issues for possible

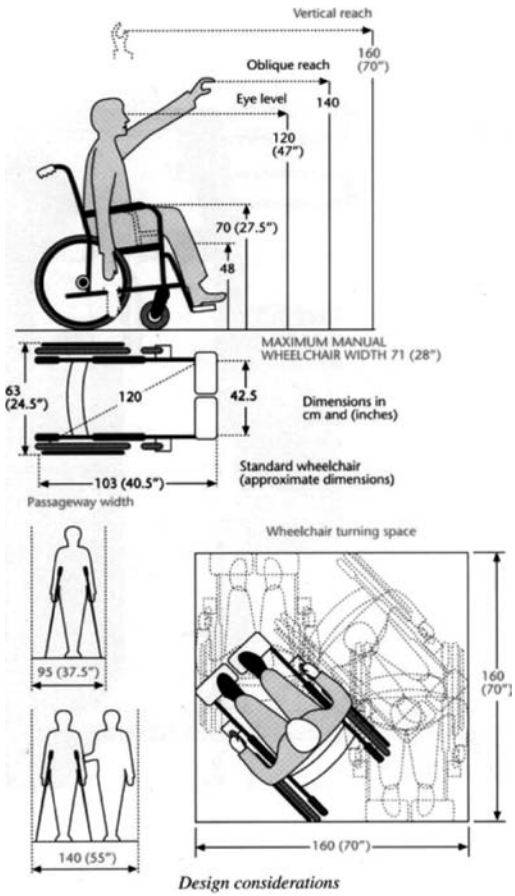

Figure 4. Some measurements to be considered when designing for disabled people (Couch et al., 2003).

clashes with reinforcements in the wall, and he validates the solution. The HVAC engineer determines that the ventilation pipe must be extended to meet the outlet in the shower. New fixtures and fittings are needed in the bathroom.

The drain from the bath tub causes the most severe problems. The shower needs a drain at the back or in the corner, which can only be created by caving a new duct. The new duct will interfere with the water supply pipe and there is no other way to lay a supply to the shower. Either, the shower must be elevated from the floor in order to make drainage under the shower floor, or they must find a shower with the possibility to manipulate the water outlet. Firstly, they try to find a match between the floor design and the shower design. None can be found, even when trying various tolerances and outlet systems. The shower has, therefore, to be elevated.

Wayne is asked to evaluate the new design. The measurements are taken into the design program and variations on the elevation combined with the drainage system are simulated. Finally they agree on a specific shower system with a 5.5 cm elevation of the shower floor with ramp to accommodate the height change.

Extra costs are calculated and verified by all stakeholders. The time schedule and work plans are also adjusted according to the new design. List of quantities are adjusted and suppliers will be semi-automatically listed for later purchase instructions. All persons whose work is affected by the changes will be listed and prepared by notification. All this information and changes are recorded in the project data space.

The meeting ends with a definitive validation and agreement of the design change, and the participants return to their everyday work. The list of actions and information updates are made available to each participant for implementation within their own organisations as required. These include annotations, red-lines, and the proposed design organised on separate layers. They are distributed to the design team who make the alterations in construction, installation and furniture in the model before selected stakeholders are invited in a distributed collaborative workspace to confirm and approve the results.

4 TECHNOLOGICAL REQUIREMENTS

The scenario has been developed by industrialists and researchers through a series a meetings. It is based on the requirements identified by professionals within the construction industry and by researchers who specialise in collaborative work. As a result, it corresponds to a realistic example of how state-of-the-art technologies could enhance collaboration.

The main requirements considered in this scenario are presented below. For each of them, the corresponding technologies proposed by the CoSpaces project are shortly described.

4.1 *Security*

A secure infrastructure is a prime requirement in the above scenario where several enterprises must collaborate to reach an agreement. Moreover, construction projects often involve many SMEs that can be involved only in small parts of the project and generally compete for other contracts. One of the key issues is to ensure IPRs' (Intellectual Property Rights) protection by assuring that any data provider has full control over its data (Kipp et al. 2008). In the above scenario, this is illustrated by the fact that any participant can define the access rights to the documents he/she shares during the meeting.

In the CoSpaces project this control over own data is reinforced by the provision of private data spaces in the system. These auto-administrated data spaces contain all the information that an organisation is willing to share during the meeting. The data placed in this space can be first uploaded in their DMZ (Demilitarised Zone), which is protected by a firewall, before it is uploaded on the shared system. In addition to these private data spaces, every stakeholder has access to a shared data space where all the documents shared during the project can be uploaded (Kipp et al. 2008).

During the meeting, every user can access a private workspace and several shared ones. The private workspace is only accessible to one user. Private data can be accessed through it, coming either from the organisation data space or from the devices owned by the user. If there is a requirement to share some information from these private documents with other participants, the user can then transfer the whole document or some parts of it in a shared workspace. The shared workspace can be made accessible to a few participants in order to discuss a particular viewpoint such as a clash between several disciplines. It can also be made accessible to all the participants in order to build up a shared understanding between all the stakeholders.

The possibility to partially share documents and to control access to workspaces provides the user with a great flexibility. It allows him/her to share a maximum of information while offering a high IPR protection. Indeed, enterprises usually prefer to share as little as possible in order to avoid any privacy issue, but this attitude limits the efficiency of collaboration which aims at building a shared understanding (Gautier et al. 2008). By allowing the user to react to unplanned developments within the meeting by sharing more information than initially intended, the outcomes of the meeting might be improved and the understanding between the stakeholders increased.

Finally, the identification system can be centralised in order to avoid the repetition of identification requests every time the user accesses a new application or data space. For instance, the Shibboleth approach permits the identification of the user the first time he joins a meeting and the automatic authentication and authorisation when trying to access the meeting resources and tools. This allows the user to concentrate on the discussions thanks to a more ubiquitous system.

4.2 *Interoperability*

Interoperability is the "ability of two or more systems or components to exchange information and to use the information that has been exchanged" (Standards coordinating committee of the IEEE computer society 1991). It is crucial for inter-enterprise collaboration such as the ones presented in the previous scenario because it allows inter-disciplinary communications. This can be partially achieved by using a standard such as IFC to create a link between the organisations involved in the project. The documents shared during the project are then associated to the components of the IFC model and the stakeholders have an adapted view on the model corresponding to their roles in the project.

However, efficient interoperability requires a reference ontology that is used for semantic mapping between enterprises (Beneventano 2008). Indeed, even if standards are used as a base for data exchange, they must often be adapted to capture the specific requirements of every organisation. The addition of a new product in any of the collaborative enterprises must also be reflected among all the partners through the ontology. Consequently, the cost of maintaining a reference ontology is often very high and it increases exponentially with the number of enterprises involved in the project. The result is that interoperability is rarely complete between disciplines, and data exchanges must often be complemented by human explanations (Gautier et al. 2008).

Interoperability is also extremely important at application level to assure both the easy integration of the collaborative system into the processes of an enterprise and the evolution of the system as new technologies appear on the market. Among the few components at this level, a collaboration broker is necessary to connect the user interface with the modules of the collaborative system. The CoSpaces platform includes five core modules that independently manage the resources, the stakeholders, their groups, their positioning and identification, and the dynamicity of the meetings.

The CoSpaces platform also considers the numerous SMEs that have a limited role in the project. These enterprises tend to have limited contact with the other stakeholders and they do not usually take part in collaborative activities. However, their expertise can be required to assess or solve particular issues. As a consequence, every stakeholder should have access to the collaborative platform through a web browser, therefore avoiding the cost of integrating new technologies into their IT infrastructure.

4.3 *Context awareness*

The user context can be defined as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" (Dey & Abowd 1999). Consequently, a user context includes his/her physical, digital and organisational environments, as well as their evolution over time which enables prediction (Gautier & Fernando 2008).

First of all, context awareness can enhance the efficiency of knowledge support tools. Relevant information can be identified in real-time by the system according to the user activities and profile. As an example, during the preparatory phase of the above scenario, context-awareness permits the automatic pre-selection of relevant people and documents for the meeting. This feature is particularly interesting for knowledge workers, who can spend a large amount of time on non-productive information-related activities (Feldman & Sherman 2001) such as searches.

Once relevant information has been identified, it must be delivered to the user in the most effective manner. This can be achieved by transmitting the information through the best available communication channel and adapting the interface look and feel to the user. This adaptivity of the user interface is achieved by following a context-aware componential approach. In the preceding scenario, it permits the seamless combination of devices. It also increases the accessibility of the interface and addresses the need to lower the mental workload of the user (Rasmussen 1986) so that they can better concentrate on the meeting discussion.

Finally, the user context can limit the emergence phenomenon due to the unpredictability of the user behaviour (Heylighen 2001). Indeed, the consideration of the user context in real-time permits an immediate reaction to any unplanned or critical situation. Such a result is achieved by considering the informal relationships between co-workers. The model of these relationships is built on top of traditional enterprise models, which aim at describing the formal processes of the collaboration as defined by the project decisional board (Gautier & Fernando 2008).

4.4 *Virtual reality*

Even if VR (Virtual Reality) only appears in the scenario when the disabled person tests the bathroom in a digital mock up, its gain for the project could be substantial. Currently, the design of such a bathroom must be tested in a physical mock up. If the design proves to be wrong, it is often too long to modify the mock up before the end of the meeting. Another meeting must then be scheduled for new tests, and a few weeks can be lost due to the lack of availability of the stakeholders. In addition to time loss, a physical mock up is more expensive than a digital one, and the project could benefit from reduced costs.

The other principal added value of VR resides in simulation. It allows the engineers to perform some tests during the meeting to validate a solution. These tests might be incomplete and require additional work back in the office, but they could be efficient enough for a prime assessment. The objective of enabling simulation during the meeting is once again to fasten the decisional process in order to avoid the need for series of meetings.

4.5 *Management of data*

Even if the scenario, similarly to the CoSpaces project, focuses on synchronous collaboration, one can argue that collaboration is a lengthy process and that it requires regular information exchanges between its stakeholders. As a consequence, the collaborative system should at least include a PDM (Product Data Management) system for asynchronous collaboration during the project. PDMs are already mature and used by the main construction organisations, and the CoSpaces project does not plan to compete with their providers. Instead, every organisation that uses a collaborative platform should connect it to its PDM in order to take the best out of the combination of these tools.

A document management system is nonetheless integrated into the CoSpaces platform to allow for the implementation of a collaborative system completely independent from the PDM. The documents could, therefore, be downloaded from the PDM to the meeting data space and used without interfering with other work. At the end of the meeting, the meeting data space would contain copies of the files modified during the meeting and the co-workers could copy the changes manually into the documents of the PDM. This approach could facilitate the acceptance of the collaborative technology by organisations because it strongly limits the risk of interoperability errors when linked to the PDM.

4.6 *Scenario implementation*

To summarise this section about the technology, Table 1 presents the technologies that CoSpaces proposes to use for the implementation of the scenario. The scenario has been decomposed into a series of actions performed by the participants. Each action is associated to the technologies necessary for its implementation.

Some of the requirements that were presented at the beginning of this paper are not covered by the scenario. This is the case of ad-hoc meetings, which allow the quick start of reactionary meetings or the possibility to invite remote experts to join the meeting as soon as they are needed. These requirements were addressed in other scenarios developed by the CoSpaces project (Gautier et al. 2007) and they illustrate the use of additional technologies such as as-hoc networks or expert finding.

5 CONCLUSION

The scenario presented here is a good illustration of the impact that human-centred technologies could have on collaborative work. The most obvious gain in this particular case would be on time, but it is reasonable to assume that improved communications

Table 1. Technology use during the scenario.

Actions	Technologies
Participants link documents to the shared workspace and select tools.	• Context aware system • File management system
Participants define access rights to the resources placed in their shared workspaces.	• File management system • Shibboleth
Participants' location and access are tracked.	• Context aware system
Configuration of the participants' locations and access provision to the meeting resources.	• Context-aware componential user interfaces • Shibboleth
Presentation of the problem and possible design solutions.	• Shared workspace • Context aware system
Participants annotate model and share viewpoints	• Flexibility of private/shared workspaces • Disciplines/enterprises interoperability
Disabled person tests the bathroom accessibility.	• Virtual reality • Simulation
Architect and engineers change the design	• Virtual reality • Interoperability with the suppliers • Context aware user interfaces
Architect and engineer exchange view points	• Shared workspaces • Context aware user interfaces • Disciplines' interoperability • Simulation
Project Manager finds out that material is ready for installation	• Project management tool
Engineers validate the new design	• Flexibility of private/shared workspaces • Simulation
Calculation of extra costs	• Project management tool • Enterprises interoperability

would also lead to more suitable decisions, and ultimately decrease the cost of the project by avoiding the over-cost of problem solving. Besides, the impact of decisions would certainly be better understood and quality would be improved. This paper shows that several advanced technologies must be combined to efficiently support collaboration, but that these technologies will soon be available on the market.

A cultural change will surely be necessary before collaboration can be exploited to its full potential in the construction industry. This is partly due to the 'blame culture' and the high involvement of SMEs, because it reduces the level of trust between partners. However, the futuristic scenario developed by the CoSpaces project intentionally follows current processes and its implementation only requires some investment in the technologies.

As stated before, the CoSpaces project does not uniquely consider the needs of the construction industry, but also works closely with partners in the automotive and aerospace sectors. The collaboration platform that has been succinctly described above is thus flexible enough to address the requirements of a range of industries. It also supports co-located and remote collaborations as well as powerful computers as much as mobile devices. Eventually, such a collaborative framework should be able to support any kind of group work because collaboration is mainly about bringing people together, and not about addressing the particularities of a contract.

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Integrating use case definitions for IFC developments

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ABSTRACT: Advantages of BIM-based working are well recognized by the AEC/FM industry, but it is still barely used in practice. It is not only to understand the idea behind BIM. There are couple of questions that have to be answered to benefit from BIM-based working. The article argues that use case definitions are a main source of information. They not only provide necessary details about available BIM solutions but also enable to integrate and maintain all kinds of BIM developments. This understanding is reflected in a number of recently published specifications of the international IFC standard. The article provides a survey of use case based IFC developments and discusses their application, identified difficulties and suggested solutions.

1 INTRODUCTION

It is widely acknowledged that Building Information Models (BIM) and buildingSMART/IFC enable significant improvements of design processes and facilitate collaboration (Howard & Bjork 2007, Kiviniemi et al. 2008). But BIM based working is not yet able to integrate all design domains or to support design processes from the very beginning to the end. IFC developments concentrate on a set of realistic use cases that provide a sound basis for further extensions. Additionally, the quality of IFC implementations is sometimes not fully compatible so that IFC-based data exchange still requires a lot of experiences (Kiviniemi 2007).

Today, BIM based working means to decide about use cases that should be supported in a specific project and thus requires substantial knowledge about the BIM software that shall be used in the project and their IFC capabilities (Bazjanac 2002). Such knowledge is starting to be reflected in different IFC guidelines describing the result of IFC extension and implementation processes. Ideally, the requirements that were initially formulated and results of IFC developments are described in the same way in order to be aware of the differences between required and implemented IFC functionality.

Typically, use case definitions are the first step of model specifications (Turk 2001) and therefore should gain special attention in the IFC development process. The aims of this paper are to explain the importance of use case definitions and to show the current situation of IFC developments and available guidelines.

1.1 *Challenges of IFC development*

The overall mission of IFC is defined to be the "... specification for sharing data throughout the project life-cycle, globally, across disciplines and across technical applications ... in the construction and facilities management industries." (www.ifcwiki.org). It is a pretty clear message but unclear about the use cases that are really supported by the current IFC release. According to the overall mission, IFC developments are faced with two challenges:

- provide a data structure that is able to fulfil the information requirements of involved disciplines
- supporting the implementation of a data structure that exceeds the scope of typical domain specific design applications

After several years of development the idea of buildingSMART is based on a huge and complex data structure, whereas always only a 'small' part is needed for specific use cases.

1.2 *Overview of the IFC development process and involved actors*

IFC development involves not only different domains of the AEC/FM industries but also professions from the IT. Each of them contributes to the IFC standard, starting from initial requirements to the final feature in a software product. Moreover, IFC is an international standard and thus has to deal with different cultural backgrounds and languages. Consequently, the specifications supporting IFC development (1) have to be defined according to the needs of involved users and (2) should enable to keep track of all kinds of IFC development, i.e. the way from initial requirements till the use of IFC interfaces.

There are basically three types of users: (1) business experts, (2) modelling specialists and (3) software developers. Each of them can be assigned to one of the ten pillars of IFC development (Liebich 2007), which address four main areas:

- Business requirement specification
- IFC extension modelling
- Use case implementation
- End user guidance

It is a sequential process that is typically done in the given order, i.e. it starts with requirements and ends with user guidelines. Each step tries to reuse existing specifications so that a gap analysis is one of first and main activities in all of these areas. Thus, before starting a new development it is important to get familiar with the overall methodology and the specifications that already exist.

1.3 *Structure of the paper*

The paper is inspired by the InPro project (www.inpro-project.eu) that aims at introducing BIM based working in early design. One of the first tasks was to define business processes that are of interest to be supported and optimized by a shared BIM. It is the start for further IFC developments that are discussed in paper, i.e. each of the four main areas are presented together with specifications being used for a gap analysis and the work that has to be carried out in the project.

It is worth mentioning that the methodology of IFC development is principally agreed within the IAI. However, not all details of required specifications are fixed yet. There are a couple of new proposals and agreements about intertwining them, but there is a lack of experiences in using these specifications. Therefore, their application, identified difficulties and suggested solutions are discussed in the end of each section.

2 BUSINESS REQUIREMENT SPECIFICATION

Business requirements demand improvements of the current situation and thus initiate further developments. It is business experts who know the shortcomings of their daily work and therefore should play the main role in the first step of model developments.

The purpose of IFC is to provide design information that is needed to fulfil specific design activities such as energy analysis, quantity take-off etc. Traditionally, requirements were mainly used to define the scope of IFC extension projects and often got lost after integration into a new IFC release. This shortcoming has been answered by the Information Delivery Manual (IDM, Wix 2006) providing a formal way for capturing business requirements and the binding to a product data model.

The work that has been done so far with the IDM methodology (idm.buildingsmart.no) is motivated by making a more user friendly start in using BIM and IFC in design projects. These developments were brought forward by the Norwegian chapter of the IAI and the HITOS project (www.statsbygg.no/Prosjekt), which have specified several IDMs for different project stages, e.g. for the electrical and structural design. IDM in its pure form comprises three parts; (1) the Process Maps, (2) the Exchange Requirements and finally (3) the Functional Parts and Business Rules. Whereas these steps can be applied to any data structure there are additional agreements for IFC developments aiming at a tight integration with the IFC implementation and certification process.

2.1 *Process Maps*

Process Maps (PM) define the processes, responsible actors and the data flow that shall be supported by the BIM approach. The IDM guide (Wix 2007) recommends to use the Business Process Modelling Notation (BPMN, www.bpmn.org), which was developed by the Object Management Group (OMG) with the aim to provide a unified process modelling notation. Accordingly, BPMN has merged appropriate ideas from a number of prior process modelling notations including IDEF0 (www.idef.com), which is traditionally used for STEP developments (ISO 10303).

IDM also gives recommendations how to use BPMN for AEC/FM developments, which also provides a set of actor roles and project stages, for example according to the Omniclass classification (www.omniclass.ca) and standards such as the RIBA in the UK, the German HOAI and the Generic Process Protocol (ISO 22263). Furthermore, it defines how to connect tasks with the BIM and other data sources. The process information is assigned to swim lanes, which either contain the tasks of an actor or the Exchange Requirements of a data source. Accordingly, the BIM has its own swim lane that identifies the requirements of the tasks, i.e. their input and output. Additionally, tasks can be connected to each other to define a logical sequence of activities, which is also used to attach further information such as events (messages, timer, rules, etc.) or gateways defining branching and merging of tasks. It is also possible to refine tasks by introducing sub-processes that enable to be as detailed as necessary while keeping the complexity of each Process Map on readable level. Thus, BPMN provides the typical features for process modelling that are defined according to the state-of-the-art in the IT.

Process modelling is not yet in focus of BIM developments but is gaining more and more interest as it provides the basis to improve the management of BIM data. For instance, the InPro project was starting with process definitions to figure out the use of BIM in early design and to derive further requirements (Outters & Verhofstad 2007).

The initially specified Process Maps enabled a good start for further developments but left-out a couple

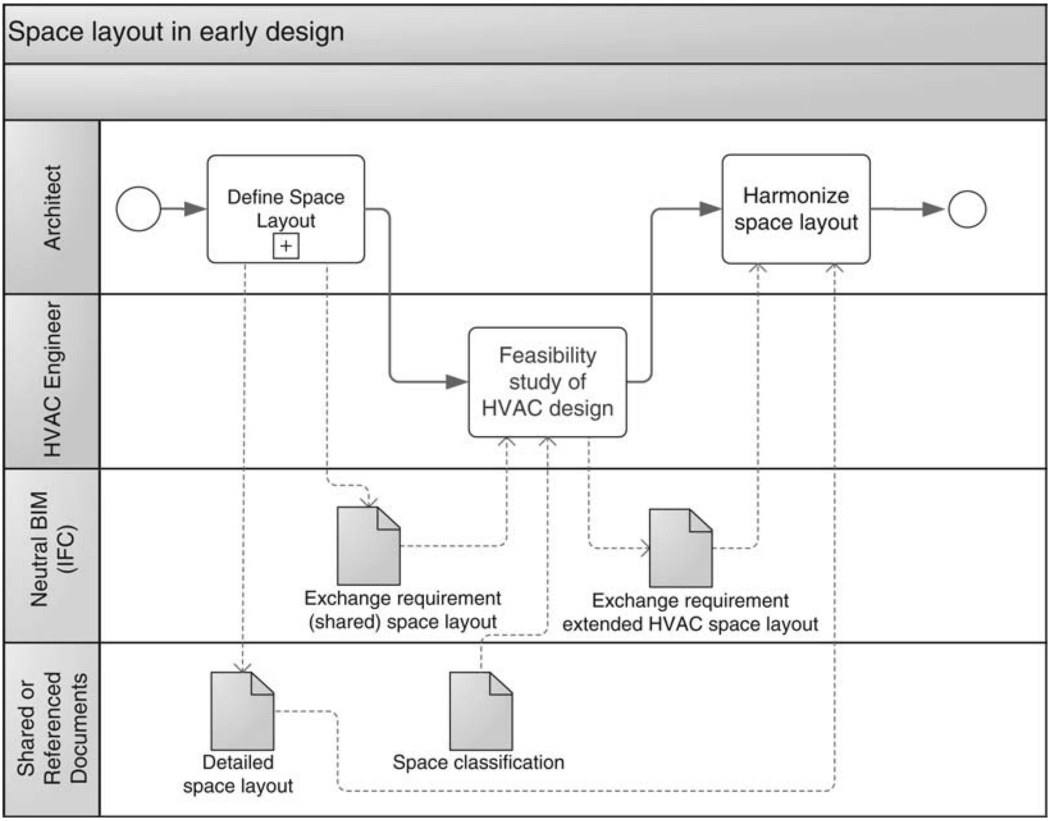

Figure 1. Simplified example of a Process Map with two swim lanes for the processes and responsible actors and two swim lanes for the Exchange Requirements and expected data sources (Liebich & Weise 2008).

of IT-related questions that are necessary to extend IFC and to implement a workflow-based data management system. Accordingly, refinements of the generic Process Maps were initiated with two aims: (1) to figure out the dependencies between different business processes and (2) to be specific enough for implementation. It also means making a reasonable differentiation between BIM requirements and requirements for other data sources such as unstructured text documents or highly specialized domain models as shown in Figure 1.

The specification of Process Maps is faced with two main problems: (1) to find a proper level between generalization and specialization of processes and (2) to manage all details needed for implementation. Executable processes soon become too complex for business experts as they typically include too much IT-related information. Furthermore, the combination of independently defined processes might be automatically deduced from Exchange Requirements, but due to often mismatching definitions it is not really practicable. Thus, dependencies between process maps have to be defined by hand, which also increases the complexity of process definitions.

2.2 *Exchange Requirements*

Whereas Process Maps identify required information by unique names and assign them to tasks, either as input or output, all details of the requirements are described in an Exchange Requirement (ER) that are defined by business experts. Therefore, Exchange Requirements are always described according to business concepts that have to be mapped to IFC or other data structures.

Required information is typically provided in tables that help to structure requirements, to define further details about the concepts and to differentiate between required, mandatory and optional information. Similar to Process Maps that identify Exchange Requirements of tasks the Exchange Requirements can set a link to reusable IT concepts, the so called Functional Parts, which provide further details about the implementation of business concepts.

So far, most work on Exchange Requirements has been done in the HITOS project, also showing the link to Functional Parts. Consequently, they roughly include the mapping to the data structure, which has to be added by the modelling specialists. But here there is some overlap with the *Model View Definition* format (MVD, Hietanen 2006), which has been developed to support the implementation of IFC use cases.

The overlap between both stand-alone approaches has been eliminated by the harmonised IDM/MVD approach, which will be used by the InPro project and means to reuse the concept definitions of the Exchange Requirements in the development of MVDs, i.e. the release independent part of an MVD. The difference between both parts remains for the specification of business rules, which are related to business processes and thus to the ERs, and the further detailing of business concepts, which is necessary to support the implementation of IFC.

2.3 *Functional parts and business rules*

The purpose of Functional Parts (FP) is to define reusable IT modules that describe the implementation of Exchange Requirements. They can be grouped together to create new Functional Parts and thus can be defined on any appropriate level that helps improving reusability. Furthermore, Business Rules are added to Functional Parts to specify consistency and completeness of required data, which in case of using a machine interpretable specification would enable an automatic checking of IFC data, as shown in the CORENET project (www.corenet.gov.sg).

The harmonized IDM/MVD approach partially shifts the content of Functional Parts to a Model View Definition so that all process related requirements and rules are specified in the so called Exchange Requirements Model (ERM). There is no recommendation for using a particular specification for the definition of IFC subsets or Business Rules. However, as IFC borrows many concepts from the STEP standard available developments mainly have been based on EXPRESS (ISO 10303-11) and EXPRESS-X (Denno 1999).

Exchange Requirement Models are of particular interest for implementation of a data sharing environment, especially if the process-related knowledge is available in a machine interpretable form. Such knowledge is gaining more and more interest for controlling the quality and the increasing complexity of BIM-based design data. The main sources for data validation are building codes, regulations and additional agreements that have to be fulfilled to deal with national, local or project specific requirements.

The identification and coding of Business Rules are for instance targeted by the SMARTcodes™ technology (www.iccsafe.org/SMARTcodes), which addresses the problem of making machine interpretable rules out of paper-based codes and regulations. The availability of such rules would further raise the benefit of BIM-based working. However, this kind of development, which should based on an efficient rule coding strategy, is not in focus of InPro and therefore is discussed for selected examples only to show the benefit of such Business Rules.

3 IFC EXTENSION MODELLING

The IFC model shall provide the basis for the exchange of BIM-data as defined by the Business Processes and related BIM requirements. Accordingly, if the current IFC release is not able to support these requirements it has to be extended by using one of the three extension mechanisms of the IFC platform. An IFC extension has to be coordinated with the Model Support Group of the IAI (MSG), which decides about appropriate extension strategies and the scope of the next IFC release.

The main actors of IFC extensions are modelling specialists, who are familiar with the IFC data structure and the modelling concepts. Furthermore, they are responsible for the mapping of Exchange Requirements to IFC, which is first step of any IFC extension project as it enables to identify existing gaps.

3.1 *Gap analysis*

The IFC documentation is actually a set of different specifications comprising:

- a machine interpretable schema definition that is available in EXPRESS (ISO 10303-11) and XML schema,
- the documentation of the IFC schema describing the meaning of entities, attributes and references,
- a set of implementation guidelines and additional agreements that restrict the use of IFC for specific purposes (Liebich 2004, www.iai.fhm.edu).

All these specifications have to be analysed for the mapping of Exchange Requirements to IFC in order to follow the goal of defining a BIM-based data integration standard. Furthermore, identified gaps shall be compared with the scope of ongoing IFC extension projects (www.iai-tech.org) to avoid double work and to join international efforts.

In order to achieve practical results the definition of BIM-related Exchange Requirements should bear in mind that there might be different priorities of IFC extensions, which would enable to set-up an extension strategy that first concentrates on most important requirements. Accordingly, IFC extension modelling basically has to find reasonable solutions that would fit to the overall constraints of the extension project, e.g. available resources, complexity of the implementation, interest of the industry, expected time frame for the take-up of results, plans for future extensions etc.

The Business Processes of InPro concentrate on the early design, which has not yet gained much attention in IFC developments. However, some Exchange Requirements can easily be handled by IFC as they only ask for a lower level of detail, e.g. for architectural and HVAC design. But some of them are not yet in scope of IFC, such as client requirements management, cost estimation or new approaches for BIM-based scheduling. As InPro aims to start with BIM-based working in early design phases it also requires major changes of collaborative processes. In order to make a first step towards improved processes it is necessary to concentrate on data exchange scenarios that either continue ongoing IFC developments or can be implemented in prototypes within the project.

3.2 *IFC schema extensions*

IFC2x3 contains 653 entity and 327 type definitions, and meanwhile supports 9 domains. The IFC schema is divided into 44 sub schemata and the classification of entities is sometimes based on 8 specialization steps. This kind of modelling is based on the object-oriented approach and has been chosen to improve extensibility of the data structure. Thus, new entities and types shall be defined according to the overall IFC architecture and shall reuse existing specifications.

The IAI has defined a couple modelling constraints such as the ladder principle, single inheritance or the substitution principle of Liskow that are explained in the IFC modelling guidelines (Wix & See 1999). Furthermore, a new IFC release should ensure upward compatibility with the previous IFC release, in particular to the IFC platform to avoid conflicts when moving to a new release.

IFC schema extensions are long-term developments that depend on the IFC release cycles and have to be discussed with the Model Support Group of the IAI. It typically requires two or more years to integrate proposed extensions in a new IFC release, which then would enable to start the implementation. This time frame does not really fit to research projects like InPro, which have to start prototype developments within one or two years. Therefore, if possible the strategy of InPro is to avoid schema extensions, which means to use property sets, proxy elements and references to external data structures.

3.3 *Use of property sets and proxy elements*

Property sets and proxy elements enable to extend the scope of IFC without changing the schema, but require additional implementation agreements about the meaning of properties and proxies if they shall be shared with other CAD software. A single property is key-value pair that can be attached to nearly any kind of elements and thus enables to extend their attributes. A proxy element is an object that inherits main functionality from its super type like for instance a building element, but without having a predefined meaning. The meaning or class type is described by the name attribute, which enables to introduce new element types.

The dynamic extension mechanism comes with the risk that the IFC standard evolves into different dialects that are only agreed between few partners and finally results in incompatible IFC files. As naming of properties and proxies typically depends on the context and language in which they are used there are always naming conflicts that are often leading to unusual definitions. However, the naming problem is going to be changed in IFC2x4, which supports multilingual property sets and links to dictionaries that for instance can be based on the International Framework for Dictionaries (IFD, ISO 12006). Such ‘mapping tables’ would help to make name-based extensions more understandable as they can be provided in different languages.

3.4 *References to external data*

The BIM approach is not claiming to support any kind of design data and thus to replace other data structures. Instead, the focus of the IFC standard is to provide a shared database that helps to integrate and manage the design data, whereas integration could also mean to set links to external data sources that contain very special domain information or further specify the shared data according to product catalogues, classification systems or national standards. Therefore, a BIM can be seen as a single point of coordination that enables to exchange shared information as well as to manage dependencies to other data sources.

As IFC already enables links to be set to external data, it is mainly a question of where and how to make use of such links. They might also enable a less radical cut between the traditional way of design and the BIM approach. The InPro partners agree that the ability to coexist with traditional documents is an important success factor for BIM-based working since this also takes care of the current situation that is only going to change rather slowly in the highly fragmented AEC industry. Therefore, InPro focuses on solutions that might be seen as an intermediate step, but would enable a smooth change to the BIM approach.

4 USE CASE IMPLEMENTATION

Use cases to be supported by BIM-based working are defined by the Process Maps and related Exchange Requirements. These requirements are then matched with the IFC specification to check whether it can be supported or has to be extended. The next logical step is the use case implementation, which has to make sure that each use case is implemented according to the IFC specification and all additional agreements. But it is typically only a subset of IFC that is needed to support a specific use case. Furthermore, the IFC specification might have to be clarified in that context to avoid misinterpretation and thus different implementations. Accordingly, the software industry is asking for implementation guidelines that allow to focus on use cases and guarantees compatibility with other software implementations.

There are several additional agreements and specifications that are necessary to provide adequate support of the implementation process. They are defined and discussed within the Implementer Support Group (ISG) of the IAI, which is also responsible for the certification process that finally controls the quality of software implementations. Based on experiences of several years of implementation support the IAI has decided to establish the Model View Definition format (MVD, Hietanen 2006), which provides a basis for use case implementations. Furthermore, it is dealing with the documentation of certification results and maintenance issues that for instance are necessary in case of new software and IFC releases.

4.1 *Model View Definitions*

The MVD format is divided into two main parts, (1) the generic part and (2) the IFC release specific part. Whereas the IFC release specific part provides the functionality that was previously captured in spreadsheets and additional implementation agreements the generic part was not covered by previous specifications. Both parts enable to bridge the gap between the Exchange Requirements and the IFC specification as they "translate" the business language to the IFC data structure. This connection is very important as it not only specifies how to implement our requirements but also enables that software developers can speak with business experts, i.e. to give feedback about the implementation.

There are a couple of view definitions that are discussed within the ISG. At the moment the most important one is the Coordination View that is the basis for available CAD implementations and the definition of further sub-views. They are defined in the 'traditional' way, i.e. with spreadsheets and a set of additional agreements, and gave valuable input to the development of the MVD format. The MVD format is used for new developments such as the "Structural design to structural analysis" or "Architectural design to thermal simulation" (www.blis-project.org/IAI-MVD). The time will show if the new format will be accepted in practice and if a reasonable amount of reusability can be reached to speed up view definitions and software developments.

The InPro project is one of the first users of the harmonised IDM/MVD approach, which opens a couple of interesting research issues. There are for instance good reasons to merge Exchange Requirements with the generic part of an MVD, which could reduce the number of specifications of use case based IFC developments. Furthermore, the 'same' Exchange Requirements might be defined in different languages so that national requirements could be much better integrated into international IFC developments. It even might be possible to deal with requirements from proprietary data structures of the CAD software that would help to clarify the mapping to and from IFC. This might contributes to the question how to benefit from IFD and ontology developments in context of IFC.

4.2 *Test beds*

At some point of the IFC implementation the availability of proven examples are necessary to run through test cases that allow checking implemented IFC interfaces. Software developers are frequently asking for test files as it obviously supports the understanding of the IFC specification and not at least are needed for later certification. Accordingly, setting-up a test bed is important to ensure compatibility of software implementations and thus has to take care that all relevant conditions of practical data exchange are covered. However, the request for completeness most often contradicts to available resources so that the definition of a test bed has to concentrate on a set of well chosen and good documented test cases.

Most experiences with test-bed developments are available for the Coordination View that covers 15 main object types such as walls, beams, windows, stairs etc. A set of small artificial test cases are described for each object type checking different aspects of the implementation such as geometry, material properties, connections etc. The numbers of test cases vary from 5 (for piles and plates) to about 100 (for wall) that all are described in a spreadsheet and are available for software development and certification.

A research project like InPro it is not able to take the effort of defining complete test beds. However, some examples might be developed to explain implementation agreements as suggested for the support of needed use cases. An interesting development within the IAI is to translate implementation agreements to certification rules that enable an automatic checking of exported and round-tripped IFC models. This development could speed up the provision of valid test files and will support the later certification process. However, it does not help for the documentation and a proper composition of test cases.

4.3 *Certification*

IFC-enabled software can get a certificate from the IAI showing conformance with the quality criteria of a specific use case. Meanwhile, the IAI is using a two-step certification procedure that first tests an application with a set of artificial test files (based on the test bed) and then, after end-users have proved the application for at least 6 months, the application is tested with data from real projects. A certificate is given for passing each step and thus shows the status of the implementation.

Today, a certification step can be either passed or failed. This means that the entire use case has to be supported for getting the certificate. The MVD approach suggests a differentiation of certification results that documents all supported and failed concepts. The beauty of that solution is that it describes the capability of an interface and thus enables to decide case by case if an application is suitable for a specific data exchange scenario or not. The problem of that solution is that the end user is burdened with additional decisions, which might become too technical. Nevertheless, such information is very interesting for data management environments, which can give a warning if available data is not properly supported by an application. But that kind of tool support requires an additional specification that can be evaluated by a data management tool, not only for checking software capability but also for supporting the roundtrip of design data (Weise et al. 2004).

Similar to business rules that enable data validation there are discussions about improving the certification process using automatic checking services. However, rule-based checking services are not able to support the whole certification process as they are limited to checking data against implementation agreements. Accordingly, it is not possible to verify the understanding of the data as needed for testing the import or the roundtrip of IFC data. Whereas the import and export of IFC data is currently in focus of the certification by the IAI the InPro project wants to go forward roundtrip scenarios, for instance by limiting allowed data changes that helps to manage and update the shared database.

5 END USER GUIDANCE

All developments are worthless without proper user guidelines showing where and how to use IFC-enabled software. The initial BIM requirements have to be matched with results of the software implementation to assemble guidelines that meet national requirements. Accordingly, these guidelines are typically localized documents and are provided in the language of the end users. In essence, these documents are an indicator for the take-up of IFC developments in different countries.

User guidelines are typically less recognized by the international community as they are mainly presented to the national audience. Thus, a survey of available guidelines will help to compare achievements within different countries. Even if there are a couple of global software players who sell the same software in different countries there are noteworthy differences, either because of special demands from national authorities or because of localized tools that are able to reuse BIM data, e.g. for checking the energy consumption according to national regulations. The scope of these guidelines also reflects experiences that were made with pilot projects and thus shows what is considered to be achievable in practice.

5.1 *Finland*

Finland has gathered a lot of experience in using BIM and IFC. There are about 10 pilot projects of different scale that have been carried out in the last years to prove benefits and practicability of IFC-enabled software. Results of that study were used to define BIM requirements that are demanded from the Finish state since end of 2007. Senate properties, which is the “landlord” on behalf of the Finish government for financing, managing and operating facilities, has released a set of guidelines that show there and how to use BIM, i.e. in which domains and project stages, and to what level of detail. The guidelines are divided into nine volumes describing a long-term vision of BIM-based working, but also consider the actual status of IFC-enabled software. BIM models are currently required in all projects exceeding EUR 2 million, but are limited to architecture, visualization and cost control. Further potential use cases are MEP design, energy analysis and structural design. The guidelines are available for free download at www.senaatti.fi.

5.2 *Norway*

Norway recently put a lot of efforts in IFC developments, also focusing on state-of-the-art technologies that go beyond traditional file based data exchange. Besides extensive testing of BIM software and IFC interfaces (Lê et al. 2006, Eberg et al. 2006) the use of IFC model servers and process-driven data access are in focus of BIM related R&D projects. These efforts not only gave feedback to the software development but also facilitated the specification of business processes, related exchange requirements and the IDM methodology as such. The background of these R&D initiatives is the very ambitious goal to establish BIM-based working in a relatively short time frame.

5.3 *Singapore*

A strong argument for BIM is the provision of intelligent building data. It is not only the 3D geometry of physical elements but also the knowledge about their type, function and relationships to other elements. The authorities in Singapore very soon recognized the benefit of BIM-based working and started the development of an IFC-based automatic code checking service as part of an e-submission system. One of the outcomes was the IFC model implementation guide (Liebich 2004) that clarifies the use of IFC and thus gave valuable input to the worldwide implementation of IFC. Furthermore, important experiences could be made about coding of rules and the presentation of compliance checks to the end users. These experiences are now taken up by similar developments, for instance from International Code Council (ICC). Further information about the actual status of the code checking service can be found at www.corenet.gov.sg.

5.4 *USA*

The developments in the USA are focused on introducing BIM for improving maintenance and operation of governmental properties. The General Service Administration (GSA), which manages about 32 million square meters of workspace for the civilian federal government, has established a 3D-4D-BIM program that comprises the definition of a BIM guide, BIM pilot application on current capital projects and a contractual language for 3D-4D-BIM adoption. Thus, BIM and IFC are seen as a rewarding investment that is driven by the FM sector, but will facilitate the implementation and use of IFC in whole AEC sector. More details are provided at the web site www.gsa.gov/bim.

Another focus is code checking, which is undertaken by the International Code Council (ICC). In addition to the developments in Singapore the coding of rules became the main challenge of the project, i.e. the transformation of thousands of paper based codes into machine interpretable rules. The answer to that problem is the SMARTcodes™technology, which not only can speed-up the transformation of codes but also improves clearness and maintainability of rules. Further information can be found at the web site www.iccsafe.org/SMARTcodes/.

5.5 *Denmark*

Denmark recently published a list of requirements that shall stimulate the use of modern ICT. These ICT requirements include recommendations regarding BIM and IFC. Depending on the size of a construction project there are different degrees of requirements, e.g. construction projects above EUR 2 million can demand building models in IFC format as as-built information and above EUR 5.3 million shall demand them in design competitions and detailed design. Further information about these requirements can be found at detdigitalebyggeri.dk.

5.6 *Germany*

In Germany, the initiative for providing a comprehensive user guideline mainly came from the German speaking chapter of the IAI and was supported by the software industry in a joint effort. The aims of this guideline are to show the advantages of BIM-based working and to lower the barrier for using such technology. It tries to convince end users to make a start in gathering BIM experiences and gives very practical information about IFC-based data exchange. For instance, a small example was chosen to describe the import and export functionality of available CAD software and enables to play with their interfaces. The user guideline and all examples are available for free download at www.buildingsmart.de.

6 CONCLUSION

It has been shown that IFC developments are far more than defining a data structure that is supported by CAD interfaces. An answer to emerging problems of the BIM approach are provided by use case based developments. They enable integration of all parties that are involved in IFC developments, i.e. the requirements definition, the model specification, the software implementation and last not least the definition of user guidelines. Each component of these developments is already covered by the IAI but yet have to be further tested, integrated and used in broad scale. Thus, even though the general approach provides a sound basis for further IFC extension developments, there are still a lot of questions for making it robust and reliable.

The InPro project is running through the whole process of IFC extension developments and tries to apply the described approach. Therefore, we expect to get valuable experiences that help to give feedback to the IAI. Besides technical questions such as scalability, reusability and consistency the aim of our research is to improve the communication between the different types of users, so that for instance the architect better understands for which processes he actually can use IFC-enabled software or the modelling expert can keep the link to business requirements. As IFC developments are never finished, i.e. they are steadily going through refinements and have to be updated, the integration that is facilitated by use case based developments will become a crucial issue for improving the maintainability of IFC.

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The COMMUNIC project virtual prototyping for infrastructure design and concurrent engineering

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ABSTRACT: The main objective of the COMMUNIC R&D project, developed in cooperation between EGIS (coordinator), Armines, Bouygues Travaux Publics, CSTB, Eiffage TP, Vinci Construction France, IREX, LCPC, SETEC TPI and University of Marne La Vallee partly funded by the French National Research Agency, is to develop and experiment a new methodology based on virtual prototyping for concurrent engineering and cross communication between actors of infrastructures (roads, bridges . . .) design and construction.

1 INTRODUCTION

1.1 *Problem status*

The design, construction and operation of an infrastructure involve a large number of stakeholders (designers, urban developers, asset managers, local authorities, control offices, construction companies, environment experts, citizens . . .) and require more and more cross communications between these actors in order to insure a good construction with the respect of durable development objectives. Communication based only on documents and 2D-drawings has now reached its limits and it is time to introduce new working methods based, in particular, on virtual prototyping which has proved its capacity in other industrial sectors like aeronautic or automotive.

1.2 *Approach and methods*

The COMMUNIC project is divided in 5 tasks:

Task 1: General technical coordination of the project. This task is performed by EGIS.
Task 2: Global model: Objective of this task is to identify the global processes and objects data models to be used for concurrent engineering of infrastructures using a virtual prototype.
Task 3: Use cases and added values: Objective of this task is to identify the use cases and potential added values of a multi-usage virtual prototype for infrastructures design and concurrent engineering.
Task 4: Experimentation: Objective of this task is to develop some first prototypes of infrastructures virtual prototypes for experimentation and on the ground testing of the results of task 2 and 3 studies.
Task 5: Dissemination: Objective of this task is dissemination of the project. This current workshop participates to this task.

1.3 *Results and perspectives*

Expected results of the COMMUNIC project are the following:

- International data model proposal for infrastructures building: inputs of the IFC Roads project;
- Statement of work for development of industrial software tools for virtual prototypes dedicated to infrastructures design and concurrent engineering;

Demonstrators of infrastructures virtual prototypes.

2 GLOBAL MODEL

Objective of task 2 is to identify the global processes and objects data models to be used for concurrent engineering of infrastructures using a virtual prototype.

2.1 *Processes*

First stage of the task 2 of the COMMUNIC project consists in defining the processes for building and using a virtual prototype in the field of infrastructures construction. Some SADT schemas are used for that purpose.

2.2 *Object model*

Next step, after processes analysis is to identify the objects to be presented and exchanged between the different phases of the construction project.

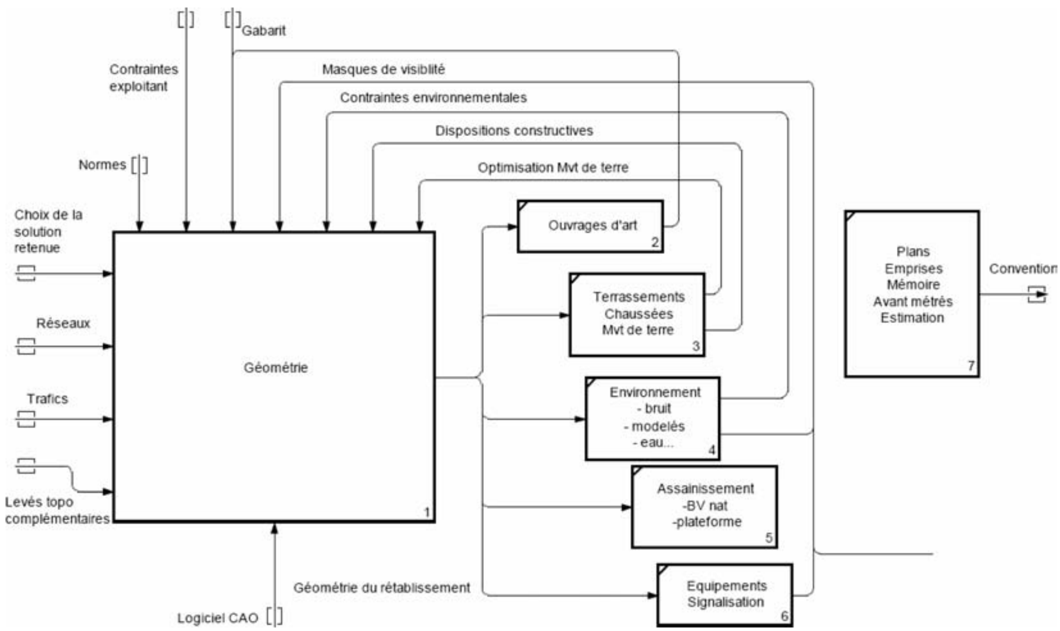


Figure 1. SADT geometry definition.

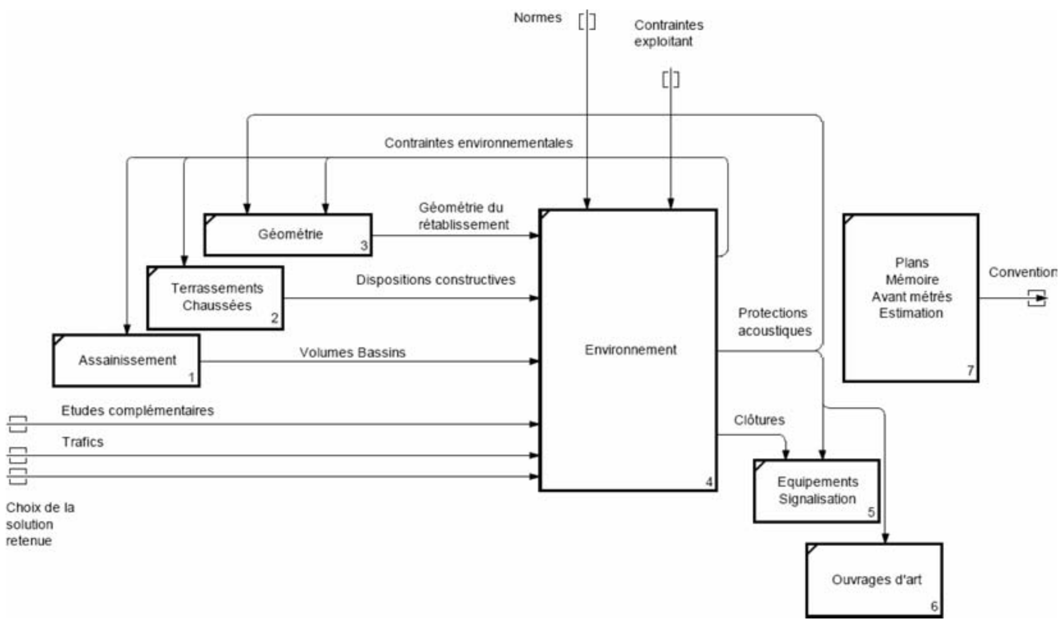


Figure 2. SADT environmental analysis.

These objects are dispatched within 5 different levels of details of the virtual prototype:

Level 0: general description of the project: financial, laws, environment (original GIS), administrative information.

Level 1: functional description: first drawing of the road, localization, planning . . .

Level 2: disciplines description: the road project is divided in different disciplines and actors (bridges, earthwork, put on, draining network . . .). Each

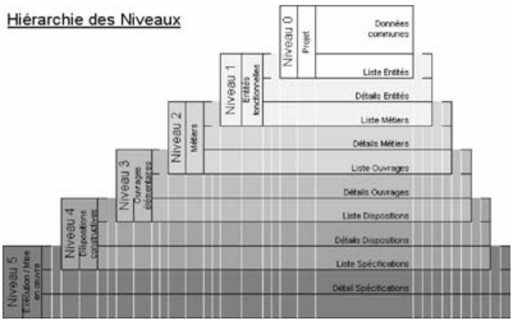


Figure 3. Virtual prototype levels.

discipline is described with specific objects and the coordination between the actors is possible.

Level 3: buildings components: each building components are detailed and the building process is defined. Global structural analyses and physical phenomena (ex: wind) are performed.

Level 4: detailed design: detailed geometry and detailed structural analyses are performed on the components.

Level 5: Execution: the construction and assembly methods are defined for the different components of the road.

2.3 *Validation*

Objective of this work is to define how the paper based validation process will be replaced by virtual prototype usage, for the different phases of the construction project.

3 USERS BENEFITS

Objective of task 3 is to identify the use cases and potential added values of a multi-usage virtual prototype for infrastructures design and concurrent engineering.

3.1 *Actors coordination*

In the field of actors' coordination, the following benefits have been identified:

- To facilitate the external data collection;
- To have data and constraints relevant and easy to recover;
- To control the interfaces;
- To better understand constraints of the other fields and other actors;
- To cause alternatives of optimization;

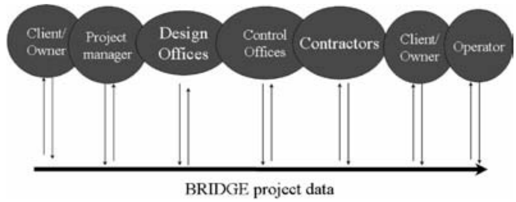


Figure 4. IFC-Bridge scope.

- To simulate as of the upstream of the phases the downstream of construction or exploitation;
- To facilitate specialized simulations;
- To make overall assessments;
- To provide data to the other actors of the design and construction;
- To facilitate the reporting;
- To accelerate decision makings;
- To facilitate the dialogues
- To communicate.

4 USAGE OF IFC

For the experimentation and future industrial implementation of COMMUNIC data exchange the IFC standard will be used. And, in particular, the IFC-Bridge and future IFC-Road extensions are dedicated to the COMMUNIC scope.

4.1 IFC-Bridge

Objective of IFC-Bridge is to carry out full development of the IFC model extensions from other IFC development projects to capture design information for providing a standard exchange and archiving model data related to the whole bridge life cycle.

Scope of IFC-Bridge model data is the following:

- General structure of bridges;
- Complete geometry definition;
- Technological definitions;
- Materials associations (Concrete, steel, wood ...);
- Pre-stressing information;
- Process control.

4.1.1 *Main characteristic of the IFC-BRIDGE data model*

The main characteristic of the IFC-BRIDGE data model, which is also the main characteristic of software tools dedicated to bridge design, is that all the specific entities can be placed relatively to the axis (the reference line – IfcBridgeReferenceLine) of the bridge, using a curvilinear X co-ordinates along this reference line. This reference line can also be the axis of the road on top of the bridge. Then, if required, the IfcBridgeAxisPlacement object can be used for the 3D position of the point on a transversal plan to the reference line:

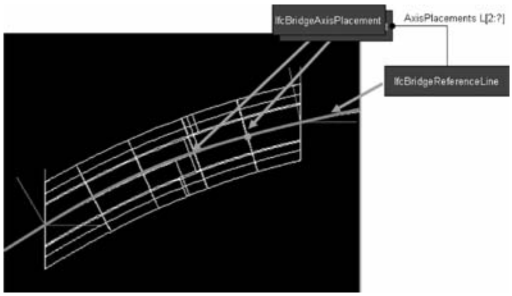


Figure 5. IFC-Bridge reference line.

4.1.2 *The IFC-Bridge Objects*

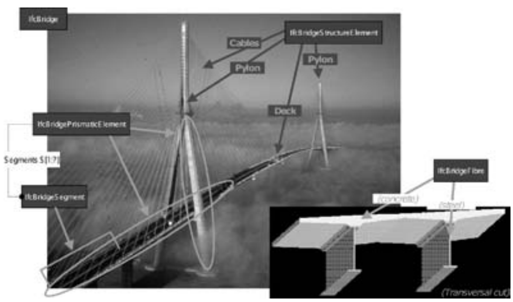


Figure 6. IFB-Bridge general structure.

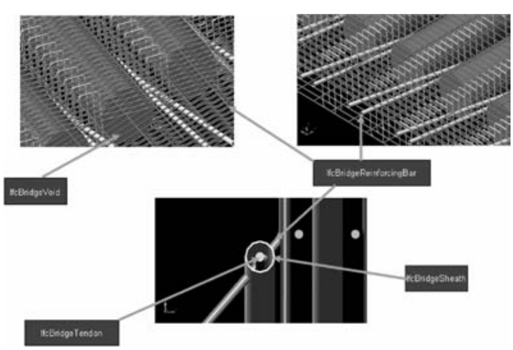


Figure 7. Bridge Element Devices.

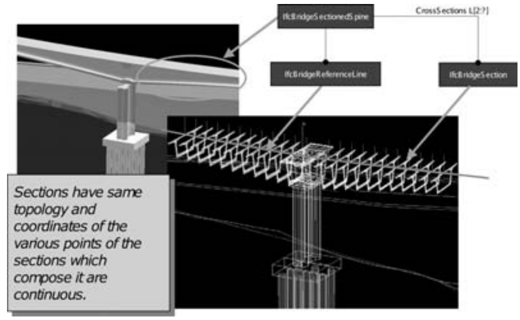


Figure 8. Bridge sectioned spine.

5 EXPERIMENTATION

Objective of task 4 (not started at the time when this paper is written) is to develop some first prototypes of infrastructures virtual prototypes for experimentation and on the ground testing of the results of task 2 and 3 studies.

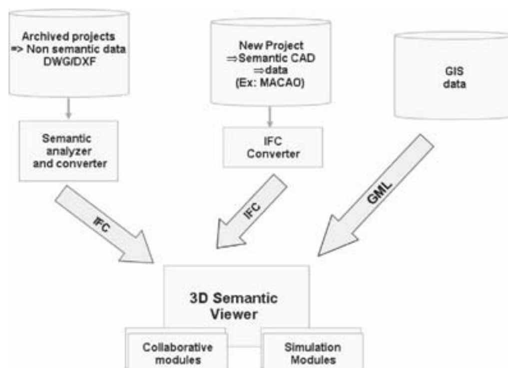
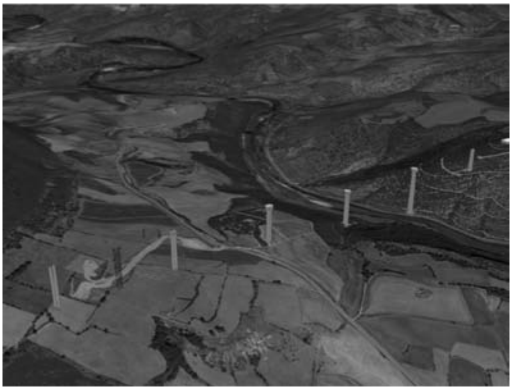
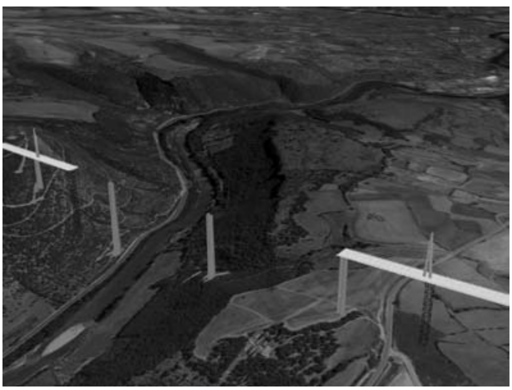


Figure 9. General architecture of the COMMUNIC demonstrator.

Then, the different phases of this demonstration should be the following:
1/ Environment analysis and first drawing of the road

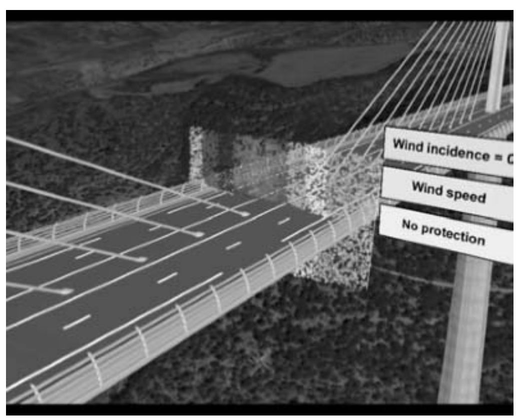
2/ Construction process simulation





3/ Detailed design and visibility simulation

4/ Physical phenomena simulations: example Wind



5/ Traffic simulation

6/ Acoustic simulation

6 CONCLUSION

At this stage of the project (1/3 of the duration), the following first lessons have been learned:

For the major construction companies involved in the project, the feeling is that virtual prototyping is going to change drastically their way of infrastructure design;

- If the construction sector is able to re-use and adapt the experience of other industries like aeronautic or automotive, some significant benefits can be expected, mainly in the collaboration between the different actors of the infrastructure project;
- The tools used in the infrastructure design chain have to be upgraded for taking into account new semantic data exchange format provided by IFC standard and actors of this design chain have to upgrade their practice to the usage of these new tools;
- The validation of the different phases of an infrastructure project design, based on this paperless methodology will require some significant adjustment of the administrative or juridical process between the actors. This is still to be defined.

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Decomposition of BIM objects for scheduling and 4D simulation

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ABSTRACT: This paper addresses the common problem of object splitting encountered when a Building Information Model (BIM) is used to support the creation and validation of construction schedules. A generalized splitting algorithm for boundary representations (b-rep) of BIM objects and an IFC based data management concept for refined object granularities are presented.

1 INTRODUCTION

As Building Information Models are getting more and more introduced into the building industry practice, the project scheduling can benefit from this new way of working. The well known 4D visualisations of completed schedules are one step in this direction (Heesom & Mahdjoubi 2004). Taking the bill of quantities into account, the BIM approach of working further eases project scheduling by supporting the calculation of individual task durations during the creation of the schedule (Aalami et al. 1998), (Tulke & Hanff 2007).

In both cases the granularity of geometry and quantity information needed is affected by the construction sequences in the schedule. In particular, if several construction schedule alternatives should be generated based on the same BIM, the object granularity must not be coarser than the greatest common partitioning needed by all schedules (Figure 1).

This often leads to conflicts as also reported by (Haymaker & Fischer 2001) , (Reinhardt et al. 2004) and (Aalami et al. 1998) since in common practice the three information components (the CAD model, the bill of quantities and the construction schedule) are neither generated in a strict sequence nor by the same actors.

At first the CAD model representing the final state of the product is created by an architect or a draftsman. In this phase the only requirement towards the information granularity is the efficiency of model creation. In the second phase the quantity take-off (QTO) specialist adds missing information to the model and assembles the bill of quantities for cost estimation. The project scheduler reuses later these quantities during scheduling to predict the durations of single tasks. Meanwhile, he reuses also the CAD model to visualize scheduling results in a 4D simulation. Resources such as labour and equipment assigned during the scheduling process are later incorporated into the cost estimates (Figure 2).

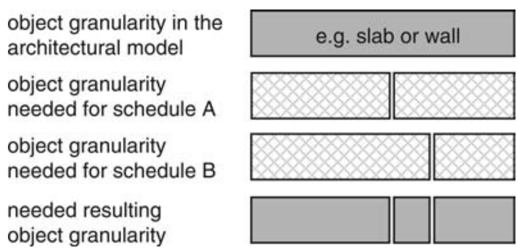

Figure 1. Scheduling impact on object granularity.

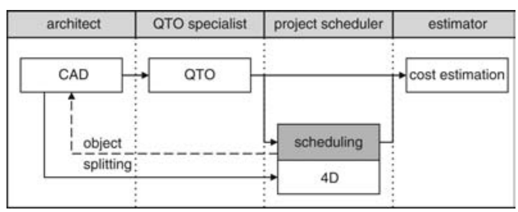

Figure 2. Process dependencies.

To enable this subsequent utilization of information, by the project scheduler, the model has to be held in a compatible object granularity. However this can not be guaranteed automatically. As a result several iteration loops in model creation and extensive coordination between the three different actors (architect/draftsman, QTO specialist and scheduler) are needed to reach an object granularity that is suitable for the three purposes. The communication overhead related to this is extremely time consuming and requires round trip modifications between actors who do not know about each other's internal working peculiarities. Consequently, the reuse of information and the adoption of model based working in the scheduling process is difficult to achieve.

To overcome this problem the project scheduler needs to have a simple to use software functionality integrated into his tool set which enables him to adjust the object granularity to his needs without intervening in other domains' way of working. Using CAD software or estimating packages for this purpose is impractical since these software packages are rather complicated and are not tailored to the needs of a project scheduler. In addition, the refined object granularity is domain specific and does not have to be taken over by the architect or estimator. These stakeholders prefer to work with the original object granularity. Thus the adjustment has to be added as optional granularity or object decomposition.

Existing scheduling and 4D simulation software does not provide such a functionality to easily add an adjusted object granularity to the scheduling domain model which is connected to the architectural design model in order to be able to react to any design changes.

1.1 *Adjustment of object granularity*

From a scheduler's perspective five different types of relations between a task in the schedule and objects in the CAD model are possible (Figure 3).

1. one task matching no CAD object (e.g. a design activity)
2. one task matching a portion of a CAD object (e.g. portion of wall W1 between axis A and B or within a zone Z)
3. one task matching exactly one CAD object (one construction element, e.g. a wall)
4. one task matching exactly several CAD objects (e.g. all walls in storey three)
5. one task matching non to several CAD objects and one to several portions of CAD objects (e.g. all walls in storey three between axis A and B or zone Z)

Whereas type one and three are easy to handle, type four can be mastered by simple aggregation (grouping) of objects without any implication on the object granularity in the CAD model, type two and five can not be dealt with by existing 4D and scheduling software tools since in these cases a splitting of one or several objects is needed.

As the project scheduler reuses the geometry for visualisation and the items from the bill of quantities

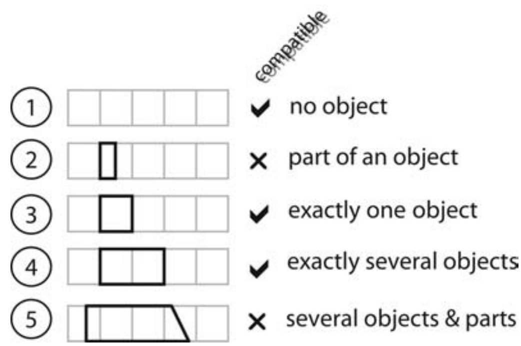

Figure 3. Possible object relations between CAD objects and a task in the schedule.

for the calculation of task durations, both information parts have to be refined. The splitting of the geometry thereby is the dominant problem since the refined quantity information can be calculated based on the new geometry parts with the same rules as used during QTO with the original object. Attributes for the part objects like material, manufacture, storey affiliation, etc. can be inherited from the original CAD object. Geometry based attributes have to be recalculated.

Once the information refinement is done, the new objects have to be incorporated into the BIM as optional, domain specific object granularity. An appropriate data management concept is needed for this.

1.2 *Requirements on geometry splitting*

Today based on 2D drawings, the project scheduler uses axial grids or zones to address parts of objects. This method is applied to all types of construction elements which are not constructed as a single unit e.g. walls or slabs. Different sections are surrounded with coloured polygons to visualize the construction sequence.

The BIM based scheduling process should support this way of working by enabling automated splitting of three dimensional CAD objects with reference to three dimensional zones. The used algorithm thereby has to be general so that it can be applied to any type of CAD object no matter what type of construction element it represents. The resulting parts of the original object have to be additionally classified as being inside or outside of the clipping zone. In this way the project scheduler is able not only to slice the product according to his needs but also to address the parts inside the clipping zone.

The need for additional user interaction compared to the 2D way of working should be kept minimal. E.g. to easily construct the zone objects, they could be defined by the end-user as a planar polygon. An additional entered extrusion direction and depth automates the construction of the three dimensional zone objects.

1.3 *Requirements on data management*

As mentioned above, the refined object granularity of the CAD model is a domain specific issue but has implications on the granularity of quantity items. Other design disciplines continue to base their work on the original object granularity. But both object granularities have to stay in relation to enable the project scheduler to react on design changes. This leads to the conclusion that in general, it is not a good practice to save the refined object granularity within the BIM. A better approach would be to use an unevaluated model approach by saving the rule behind the object refinement rather than the new objects themselves. But due to the fact that currently available software packages support explicitly saved object models only the authors found no alternative other than supporting this approach.

To limit the amount of data being stored, it is convenient to store only one refined object granularity compatible with all schedule alternatives instead of saving one specific object granularity for each schedule alternative. That is, the greatest common partitioning derived by a consecutive splitting according to the different schedule needs is stored.

To support open collaboration between the stakeholders in a project the data should be saved based on the open data exchange format IFC.

2 OBJECT SPLITTING ALGORITHM

The splitting functionality developed to fulfil the requirements explained above is based on the algorithm for Boolean operations on polyhedral objects as presented by (Laidlaw et al. 1986). This algorithm is used in many constructive solid geometry (CSG) modellers and operates on two objects at a time. In the context of object refinement the first object is the CAD object and the second one is the zone object used to address a model portion.

2.1 *Principle of boolean modeller*

These steps have to be taken to calculate the boundary representation of the result of a Boolean operation performed on two objects (Laidlaw et al. 1986):

1. Making the surface meshes of both participating objects compatible by subdividing all intersecting triangles.
2. Classification of all triangles as being inside, outside or on the surface of the other object. Triangles which are on the surface of the other object are further classified as having the same or opposite surface normal.
3. Assembling the cubature of the resulting object by selecting triangles from both objects based on their classification and the Boolean operation to be executed (Table 1 Table 1).

Table 1. Triangle selection for assembling of the resulting object of Boolean operations.

Operation	Triangles from object A	Triangles from object B
$A \cup B$	outside, same	outside
$A \cap B$	inside, same	inside
$A - B$	outside, opposite	inside*

* but inverted

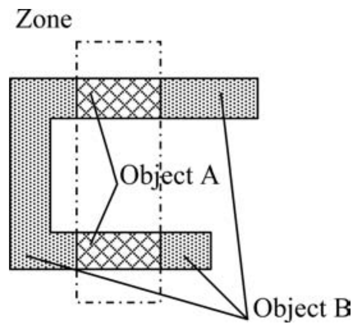

Figure 4. Objects representing the inside and outside parts in reference to the zone.

As a result of a Boolean operation a single object is always received, even if its cubature consists of strictly separated parts.

2.2 *Modification for object splitting*

Step 1 and 2 within the Boolean modeler are independent of the actual operation and have to be executed only once, even if several Boolean operations are applied on the same objects.

For the object splitting functionality two operations are used on one CAD-zone object pair: The intersection operation is used to produce the object A representing the part of the original object which is inside the cutting zone. The difference operation is used to produces the object B representing the outside part. But still, both objects can contain several separated surface meshes (Figure 4).

To fix this situation, the separated surface meshes within object A and B have to be automatically identified and transferred into separated objects.

Unfortunately the data structure commonly used for triangle meshes of b-reps allows direct access to triangle-vertices adjacency information only but not to triangle-triangle connectivity information as needed for identification of disconnected surface meshes.

For each of both objects A and B Boolean path algebra is used to calculate this relationship. Once the triangle-triangle connectivity is known, the set of strictly separated objects classified as inside or outside

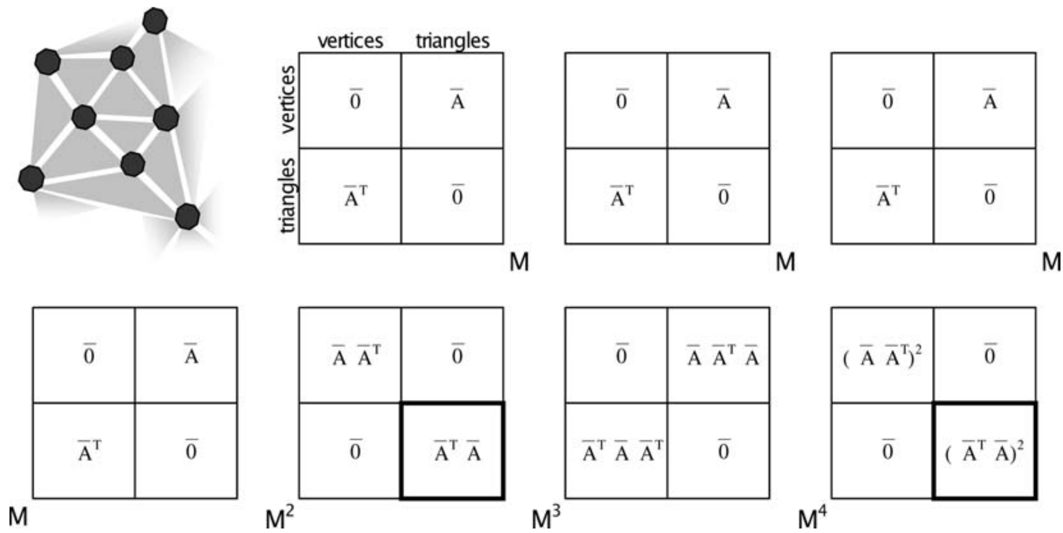

Figure 5. Principle for triangle-triangle connectivity calculation during mesh separation.

the zone can be returned as required by the splitting functionality.

2.2.1 *Mesh separation for one object*

The complete initial adjacency information of the object's surface mesh is described by the quadratic Boolean matrix M. The sub-matrix $\overline{A}$ of M with the dimension $n \times m$ represents the triangle-vertex relationship (Figure 5). Whereas n is the number of vertices and m the number of triangles in the complete surface mesh. Each column of $\overline{A}$ represents the vertex adjacency of one triangle and therefore contains true for exact three vertices. Due to symmetry, the vertex-triangle adjacency sub-matrix can be derived as $\overline{A}^T$.

The vertex-vertex adjacency sub-matrix which can be derived from the edges of the triangles is not needed and thus neglected.

The triangle-triangle adjacency information is not directly available in a common b-rep data structure. Therefore in the initial adjacency matrix M this sub-matrix is set to false, too.

That is, triangles are considered to be connected to vertices only (sketch in Figure 5).

The transitive hull H of M calculated according to equation (1) contains the complete triangle-triangle connectivity information in the lower right sub-matrix.

$$H = M \cup M^2 \cup M^3 \cup M^4 \cup \ldots \quad (1)$$

As can be seen from Figure 5 only an even power of M contributes to that sub-matrix. That is the triangle-triangle connectivity can be calculated more efficiently as hull H_D:

$$D = \overline{A}^T \overline{A} \quad (2)$$

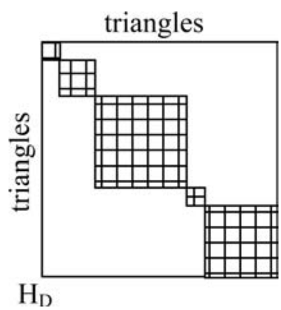

Figure 6. Separated surface meshes within H_D.

$$H_D = D \cup D^2 \cup D^3 \cup D^4 \cup \ldots \quad (3)$$

The order of triangles in $\overline{A}$ can be chosen in a way that H_D contains true only in quadratic sub matrixes around the main diagonal. Each of these quadratic sub matrixes represents a separated surface mesh contained in the object.

Thus for one row representing a specific triangle all triangles belonging to the same separated surface mesh can be found in the columns marked with true. The other surface meshes are found in the same way until all triangles have been processed.

2.3 *Implementation*

The splitting functionality was implemented in a test environment based on Java3D and a Boolean modeller implementation from (Castanheira 2003) according to the algorithm from (Laidlaw et al. 1986). The code was

```
Vector<Vector<Integer>> getSeparatedObjects(Shape3D mesh)
{
  ...
  int[] vertexIndices = new int[3*nrFaces];
  ...

  // build triangle-node adjacence matrix A
  boolean[][] tn_adjacence =
      new boolean[nrNodes][nrFaces];
  for (int i = 0; i < nrFaces; i++){
    for (int j = 0; j < 3; j++){
      tn_adjacence[vertexIndices[3 * i + j]][i] = true;
    }
  }

  // calculate adjacence matrix of triangles (AT*A)
  boolean[][] tt_adjacence =
      new boolean[nrFaces][nrFaces];
  for (int i = 0; i < nrFaces; i++){
    for (int j = 0; j < nrFaces; j++){
      for (int k = 0; k < nrNodes; k++){
        if (tn_adjacence[k][i] && tn_adjacence[k][j]){
          tt_adjacence[i][j] = true;
          continue;
        }
      }
    }
  }

  // calculate hull
  calculateHull(tt_adjacence);

  // separate objects
  Vector<Vector<Integer>> objects =
      new Vector<Vector<Integer>>();
  // outer vector = objects
  // inner vector = vertex indices ( 3 per triangle)

  HashSet<Integer> used = new HashSet<Integer>();
  for (int i = 0; i < nrFaces; i++)
  { // row of tt_adjacence
    if (used.contains(i))
      continue;
    Vector<Integer> vertices = new Vector<Integer>();
    for (int j = 0; j < nrFaces; j++)
    { // column of tt_adjacence
      if (tt_adjacence[i][j])
      {
        vertices.add(vertexIndices[3 * j]);
        vertices.add(vertexIndices[3 * j + 1]);
        vertices.add(vertexIndices[3 * j + 2]);
        used.add(j);
      }
    }
    objects.add(vertexIndices);
  }

  return objects;
}
```

Figure 7. Java code example for object separation.

enhanced as described above. An extract is presented in Figure 7.

The transitive hull H_D according to equation (2) and (3) is calculated with the Floyd-Warshall algorithm.

In a BIM coordinates of a surface mesh are often formulated in local coordinate systems. In this case both objects (the CAD and zone object) have to be transformed into a common coordinate system before executing the splitting algorithm. Afterwards both

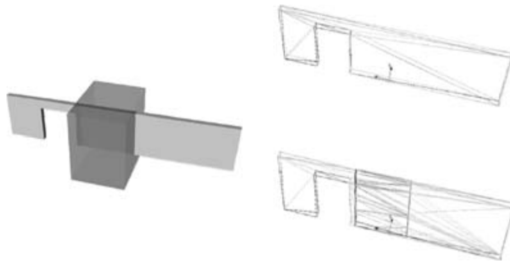

Figure 8. Object refinement of a wall.

have to be transformed back into their original coordination system.

2.4 *Remaining drawbacks*

The current implementation is based on the algorithm from (Laidlaw et al. 1986). But (Hubbard 1990) already published a much more efficient version by avoiding the local approach of surface intersecting and a more efficient classification phase. The code provided by (Castanheira 2003) which was used as basis for the test implementation doesn't consider these improvements.

Furthermore, in the current implementation the splitting functionality presuppose closed polygons (zones) as cutting objects. But in practice axial systems consisting of a set of open polygons are also used to specify cutting locations. The algorithm should be enhanced to support these cutting objects by automatically generating three dimensional zones defining the area between two specified axis.

In contrast to geometry, the splitting of object attributes could lead to an ambiguous problem e.g. for an attribute like the percentage of tiles on a wall surface. In that case user interaction is needed but a defined product ontology could help to classify attributes to be inherited from the parent, calculated from the geometry or ambiguous.

Another problem could occur when splitting compound objects which already consist of strictly separated surface meshes as e.g. windows or furniture. In this case, because of the object separation, the splitting operation produces many small parts which may be unwanted by the end-user.

Finally, to further reduce the additional effort for the end-user the object splitting and selection functionality could be encapsulated in a computer interpretable command or query language which allows to form expressions similar to the description tags used today for activities in the schedule (e.g. slab in zone A). For high rise buildings with nearly identical structures in each storey also a template based generation of those query expressions would further ease the creation of schedules and 4D simulations.

Figure 9. The multi-layering system of materials in IFC.

3 MAPPING OF REFINED OBJECT GRANULARITIES TO IFC

Parts of subdivided CAD objects are integrated into the IFC model as components of their parent through the decomposition relationship. The IfcRelDecomposes and any of its subtypes are hierarchal and a-cyclic. Any Object can be included in a single aggregation or nesting relationship. However, transitive decompositions (aggregate or nesting) are allowed. The main aim is to be able to navigate through the (whole/part) hierarchy of the object.

In the meantime, a set of CAD objects that is allocated to an activity in the construction schedule is grouped in the IFC model through a grouping relationship.

3.1 *Decomposition of objects, layering vs splitting*

Decomposition of CAD objects in the IFC model has two dimensions. First is the Layering dimension, where different layers can represent different work tasks (e.g. masonry work, plastering and painting of a wall). On the other hand, there is another dimension which is the portion or amount of work in each individual work task regardless the underlying material layers.

The first dimension is mapped into the IFC model through the IfcMaterialLayerSet which defines the relative positioning of individual layers relative to an axis (IAI, 2006).

Figure 9 shows how different material layers are positioned in reference to each other. Meanwhile, the IfcMaterialDefinitionRepresentation entity allows for multiple presentations for the same material for different geometric representation contexts that suit the 4D simulation requirements.

3.2 *Grouping and splitting*

On the second dimension there is a need to be able to subdivide objects into smaller components or group them to form larger units according to the corresponding work task in the construction schedule on the basis of volumes or clipping zones regardless of the material layers.

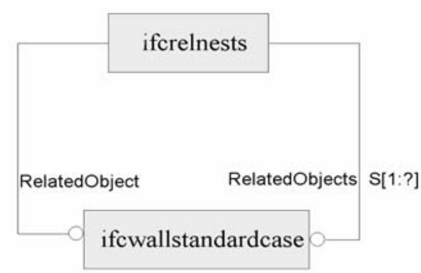

Figure 10. An EXPRESS-G diagram showing the nesting of objects.

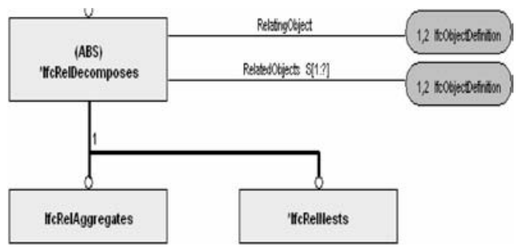

Figure 11. An EXPRESS-G diagram showing the nesting and aggregation relationships.

3.2.1 *Grouping of objects*

Grouping of several objects to be allocated to one work task is done by using the IFC relationship (IfcRelAggregates). It is worth mentioning that this relation is also capable of grouping objects that are not of the same type. The only prerequisite is the logical dependency. If the logical dependencies between the objects fail to exist, then the more general grouping concept of the IFC model can be used (IfcGroup and IfcRelAssignsToGroup).

3.2.2 *Splitting algorithm*

Splitting of CAD objects in IFC model is much more awkward than grouping. The decomposition relationship that is used in the splitting process is the IfcRelNests relationship, as shown in Figure 11. It only allows for nesting objects of the same type. This means that a wall must be decomposed to walls, a beam to beams and so forth as shown in the EXPRESS-G diagram in Figure 10.

In the case of mixing objects to suit the objects within a given work task, it is mandatory to use the grouping relation IfcRelAggregates as the nesting relationship does not permit mixing different types of objects.

Figure 11 shows the decomposition mechanism in the IFC model. Both the nesting and aggregation relationships are derived from the abstract entity (IfcRelDecomposes).

```
DATA;
#114= IFCWALLSTANDARDCASE
('10iC4Sf6zBK9yE8ZwTDQPu',#56,'Wall_A2',
'SecondChild',$,$,$,$,$);
#40= IFCPERSON ('personID', 'personFamily-
Name', 'personGivenName', $,$,$,$,$);
#42= IFCORGANIZATION ('Organiza-
tionID','OrganizationName','Description',$
,$);
#135= IFCRELNESTS
('1gdl3QG7L1KhRdK7oR9i15',#56,'Decompostio
nRelation','This Rlation Manages the Nest-
ing',#76,(#114,#95));
#95= IFCWALLSTANDARDCASE
('0$Hmk2osb6GeTsZHv3PCcE',#56,'Wall_A1',
'FirstChild',$,$,$,$,$);
#56= IFCOWNERHISTORY
($,#53,$,..NOCHANGE..,$,$,$,1178130842);
#76= IFCWALLSTANDARDCASE
('1_nE7A_FvFRuRxE1rUeAo6',#56,'Wall_A0',
'ParentWall',$,$,$,$,$);
#53= IFCAPPLICATION
(#42,'TestVersion','TestApplication','Test
ID');
ENDSEC;
```

Figure 12. A STEP-21 example showing the decomposition of a wall "A0" to two children walls "A1" and "A2".

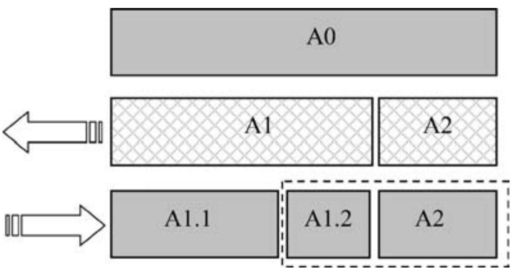

Figure 13. Replacing the domain specific object granularity in the IFC STEP file.

Figure 12 shows how the nesting relationship of walls is exchanged through the IFC STEP-21 (IS0 10303-P21, 1994) format.

It is clear from Figure 13 that the parent IfcWall-StandardCase (A0) is subdivided into two children walls (A1 and A2). To reduce the complexity of splitting objects, it has been decided to include only one level of split children objects. If the 4D simulation and the optimisation of the construction schedule require a deeper degree of granularity, then the new granularity replaces the old one and acts as the degree of granularity that can serve the production of more simulation alternatives (Figure 13).

Figure 13 shows how the IFC model is updated to include a deeper degree of granularity of the split CAD object. Object A1 is substituted by both A1.1 and A1.2. In the meantime, object A2 remains as it is. If a single work task addresses A2 and A1.2, then a new grouping is formed to include both of them. This grouping is allocated to the work task (IfcTask) through the IFC relationship IfcRelAssignsToProcess.

In this manner, the project scheduler can simulate different combinations and routes of construction for optimization reasons.

4 CONCLUSIONS AND FURTHER RESEARCH

To reduce the inter process communication between different actors during the creation of 4D simulations a general object splitting and related data management concept was developed to enable project schedulers to address model portions independent from the original CAD object granularity. User defined, three dimensional zones are used to specify these model parts which should be linked to a task in the construction schedule.

Based on such a request, the boundary representation (geometry) of the affected CAD elements is split automatically into a lower object granularity. The new objects are added to the model as parts of the parent object and can be used to calculate lower granular quantities which are needed for scheduling. The concept thereby allows supporting several alternative construction schedules through a greatest common object granularities approach which is managed within IFC and exchanged through IFC-STEP ISO 10303-P21 files. Because of the parent child relationship the new domain specific objects can be integrated in update cycles.

The main outcome of this research work is expected to be an interactive BIM editor dedicated to the project scheduler which in particular allows to easily slice the product model according to the needs of the construction schedule. The needed tools for parsing, interpreting and navigating the IFC model in an interactive 4D viewer with object splitting functionality and the ability to instantiate the IFC model with the new elements in relation to the parent elements are developed by the authors.

It is obvious that such a tool speeds up the creation time for schedules and 4D simulations. By giving the ability to investigate several different schedules for the same CAD model it also enables project optimization and thus will further promote the use of BIMs also during scheduling.

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From building information models to semantic process driven interoperability: The Journey continues

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ABSTRACT: The paper is based on the authors' involvement in several EU and UK funded collaborative research projects addressing areas ranging from information and knowledge management, CAD-based decision support environments, ontology development, to advanced service-based infrastructures. The paper advocates the migration from data-centric application integration to ontology-based business process support. The paper provides a synthesis of emerging ICT industry needs related to product data technology and proposes inter-enterprise collaboration architectures and frameworks based on semantic services, underpinned by ontology-based knowledge structures.

1 INTRODUCTION

Construction is a knowledge intensive industry characterized by its unique work settings and virtual organization like modus operandi (Rezgui 2007a). Buildings have long been designed and constructed by non co-located teams of separate firms, with various levels of IT maturity and capability, which come together for a specific project and may never work together again. Moreover, the Construction sector is fragmented and the major consequence is the difficulty to communicate effectively and efficiently among partners during a building project or between clients and suppliers of construction products. Several initiatives led by standardisation and/or industry consortia have developed data/product models aimed at facilitating data and information exchange between software applications. These efforts include STEP (ISO 1994) and the Industry Foundation Classes (IFCs) (IAI 2007). Several other initiatives at a national and European level have developed dictionaries, thesauri, and several linguistic resources focused on Construction terms to facilitate communication and improve understanding between the various stakeholders operating on a project or across the product supply chain. However, these initiatives tend to be country specific and not adapted to the multi-national nature of the sector. Also, given the vast scope of Construction, these semantic resources tend to be specialized for dedicated applications or engineering functions, e.g. product libraries and HVAC (Heating, Ventilation and Air Conditioning), respectively.

The Construction industry is still waiting for its "Esperanto" that will not only help practitioners across disciplines share common understandings and semantics about their respective areas of work, but also enable software applications to communicate seamlessly ensuring correctness and completeness of the information and knowledge exchanged. There is a belief amongst the Construction IT community that the IFCs already provide a solution to the above. In fact, the latter has evolved over time to embrace state-of-the-art research from data modelling, that emerged with the development and wide use of relational database systems and their associated techniques, to pseudo object-oriented models made popular through the wide adoption of object-oriented programming languages and design and specification environment (CASE tools), though it is not directly based on or derived from either. Some recent research has started highlighting the need for an ontology in the sector, while others have already started referring to the IFCs as being an ontology or suggesting that they be extended to become an ontology.

A comprehensive literature review targeting Computer Integrated Construction (CIC) was reported by the authors in Boddy et. al. (2007). This review reveals a strong focus on data and application integration research. It is argued that whilst valuable, such research and the software solutions it yields fall short of the potential for CIC. Thus that paper calls for re-focussing CIC research on the relatively under-represented area of semantically described and coordinated process oriented systems to better support the kind of short term virtual organisation that typifies the working environment in the construction sector. Moreover, the review provides a Framework that illustrates the CIC research landscape (Figure 1).

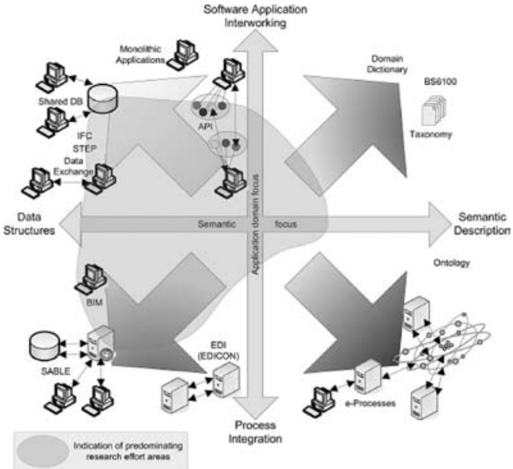

Figure 1. Computer Integrated Construction research landscape (Boddy et al., 2007).

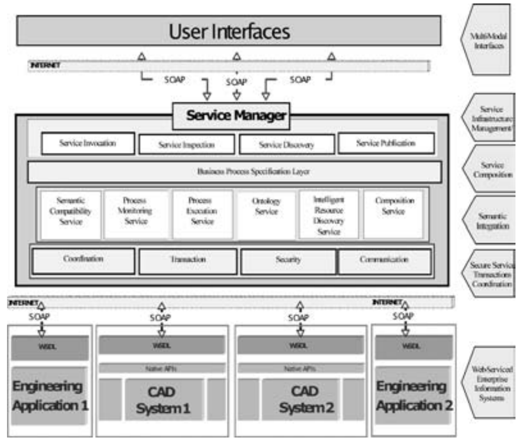

Figure 2. An ontology-based framework for e-Process execution and management.

A two dimensional representation is used, developed with respect to two axis: (a) Semantic Focus – this axis spans the whole spectrum of past, existing, and future applications with underlying semantics ranging from data structures conveyed through data models to rich-semantic representations through ontology; (b) Application Domain Focus – this axis represents the focus of research effort on a continuum from application and API centric, to process and people centric.

The paper focuses on the right-bottom quadrant of Figure 1 and argues the case for a change of emphasis from data and object centric applications to high-level process driven semantic services. The paper builds on the results of a wide consultation led by the authors in the context of the EU funded ROADCON project (Rezgui & Zarli 2006) that resulted in (a) comprehensive industry requirements, (b) an ICT vision, and (c) the first ICT roadmap for the Construction industry. In fact, the authors' research over the last decade (as illustrated in Figure 2) has evolved from advanced data and information management solutions (Rezgui et al. 1998), applied later in the context of CAD (Cooper et al. 2005), to advanced knowledge management systems, articulated around the use of an ontology (Meziane & Rezgui 2004 & Rezgui 2006), and deployed in distributed environments (Rezgui 2007a, Rezgui 2007b). Moreover, the emphasis on knowledge infused applications using service-oriented architectures has been made and reported in (Rezgui & Nefti, 2007, Rezgui & Medjdoub 2007, Rezgui 2007c).

The paper is organised as follows. First, the methodology that underpins the proposed research is presented. This is followed by a review of two decades of product data research from early product models to current so called Building Information Models (BIM). A critical discussion on product data technology is then provided arguing the case for knowledge-rich ontology. The requirements for such ontology are then provided supported by an illustration of the eCognos ontology. The paper then discusses how the ontology can play a pivotal role in enabling seamless inter-working and interoperability between diverse web-enabled applications, namely web-services, and identifies essential requirements for supporting dynamic, long lasting, processes as experienced during the design stage of a building.

2 FROM SIMPLE PRODUCT DATA TO COMPLEX BUILDING INFORMATION MODELS

Although the manual referencing of paper based product data and building design has existed for centuries, it was the increasing use of CAD facilities in design offices from the early 1980s which prompted the first efforts in electronic integration and sharing of building information and data (Boddy et al. 2007). Here, the ability to share design data and drawings electronically through either proprietary drawing formats or via later de facto standards such as DXF (Drawing / Data Exchange Format), together with the added dimension of drawing layering had substantial impacts on business processes and workflows in the construction industry (Eastman 1992). Although in these early efforts, sharing and integration was mainly limited to geometrical information (Brown et al. 1996), effectively the use of CAD files was evolving towards communicating information about a building in ways that a manually draughted or plotted drawing could not (Autodesk 2007).

This evolution continued with the introduction of object-oriented CAD in the early 1990s by companies such as AutoDesk, GraphiSoft, Bentley Systems etc. Data "objects" in these systems (doors, walls, windows, roofs, plant and equipment etc.) stored non-graphical data about a building and the third party components which it comprises "product data", in a logical structure together with the graphical representation of the building (Daniel & Director 1989). These systems often supported geometrical modelling of the building in three dimensions, which helped to automate many of the draughting tasks required to produce engineering drawings.

When combined with the increasing ubiquity of electronic networking and the Internet, this allowed many companies to collaborate and share building information and data which in turn lead to new ways of communicating and working (Bosch et al. 1991). The opportunities presented by the move towards collaborative working and information sharing encouraged a number of research projects in the early 1990's, which aimed to facilitate and provide frameworks to encourage the migration from document centred approaches towards model based, integrated systems: CONDOR (Rezgui & Cooper 1998); COMMIT (Rezgui 2007a) being examples. Similarly, the OSMOS research project aimed to develop a technical infrastructure which empowered the construction industry to move towards a computer, integrated approach (Rezgui 2007b).

It became clear that in order to take best advantage of the potential for CAD and object/product model integration, there was a need for more coordinated standards which would simplify and encourage its uptake. These standards defining efforts came in the form of the STEP application protocols for construction. This work, inspired by previous work primarily in aerospace and automotive fields, resulted in ISO 10303, part of the International Standard for the Exchange of Product Model Data. Latterly, the International Alliance for Interoperability defined the Industry Foundation Classes, a set of model constructs for the description of building elements. Preceding and in some cases concurrent with this work, the academic research community produced several integrated model definitions including GARM (Gielingh 1988), the AEC Building Systems Model (Turner 1988), ATLAS (Bohms et al. 1994), and the RATAS model (Bjork 1994). These research efforts were generally predicated on the use of either an integrated tool set also furnished by the respective projects, or on a central database holding all model data for access by any application used in the construction project process via some form of adapter (Bjork 1998). One of the most recent incarnations of the central database idea can be seen in the IFC Model Server from VTT of Finland designed to host entire building models described in the IAI IFC format.

Within the last three to four years, researchers and commercial application developers in the construction domain have started to develop tools to manipulate complex building models (Eastman & Wang 2004). By storing and managing building information as databases, building information modelling (BIM) solutions can capture, manage, and present data in ways that are appropriate for the user of that data. Because the information is stored in a logically centralised database, any changes in building information data can be logically propagated and managed by software throughout the project life cycle (Autodesk 2007). Building information modelling solutions add the management of relationships between building components beyond the object-level information in object-oriented CAD solutions. This allows information about design intent to be captured in the design process. The building information model contains not only a list of building components and locations but also the relationships that are intended between those objects (Fischer et al. 2004).

This new wave of BIM applications, embody much of the vision of previous academic research such as ATLAS, whilst still relying on data exchange standards or API level customisation for interoperability/integration. Recently, the American National Institute of Building Sciences has inaugurated a committee to look into creating a standard for lifecycle data modelling under the BIM banner (NIBS 2009). The idea here is to have a standard that identifies data requirements at different lifecycle stages in order to allow a more intelligent exchange of data between BIM enabled applications. Today, many CAD system vendors embed Building Information Modelling as a core feature of their applications.

3 PRODUCT DATA VERSUS KNOWLEDGE RICH ONTOLOGY

The progress made so far in arriving at the BIM concept and its associated tools is undoubtedly a sizeable step forward in the management, communication and leveraging of construction project information. Both the BIM models used by the commercial vendors and the international standards developed for construction such as STEP, IFC and CIS/2 do however still exhibit shortcomings as identified in Rezgui et. al., (1996) and Eastman, (1999) and from our own observations:

– As the design and indeed the domain evolves over time, so must the schema of the data model be able to evolve to accommodate these changes. Neither STEP nor the IFCs take this fully into account, though the property set construct in IFC can be employed to partially fulfil the role for certain types of information. Current BIM vendors make no mention of this notion of schema evolution in their product descriptions, thus we assume that the products do not support it.

- Different actors on a project will require views of the project data tailored to their specific role and needs. Indeed the same actor may require different views at different project stages. Whilst the lack of distinct views on the data is not necessarily a shortcoming of the models currently in use, the fact that these views and their associated semantics tend to be embedded in discipline specific applications which use the models reduces the potential for the type of flexible view configuration that we see as beneficial to project actors.
- The IFCs, STEP and to a large extent the proprietary BIM data models do not adequately cater for the notion of object ownership and rights management. Object ownership and rights should be managed at the model element level in order to record who did what and which elements were involved.
- Closely related to the previous points, support for lifecycle issues and placement of model constructs in the project lifecycle is required. For example, the list of actors that need to be notified of alterations to information changes depending upon the stage in the project at which the alterations are made. Alternatively, the initial concept design information should be superseded once detail design is started, though constant reference should be made to it in terms of verifying that initial constraints and assumptions hold true etc.
- Whilst modern BIM applications allow for the recording of 'rules' about the relationship between elements in a relatively crude fashion (door X should be 300 mm from the corner of the room etc.), support for the semantics of why such rules exist is scant to non-existent, that is to say that the intent or rationale behind the design decisions made is not recorded. The primary international standards (STEP, IFC, CIS/2 etc.) exhibit the same shortcomings.
- The relationship of model elements to other project information, particularly of the unstructured variety, is often undefined. Whilst links from within BIM applications to external information can be formed, they lack any explicit semantics. If an entire suite of tools from the same vendor is used on a project by all parties, then there are better possibilities for contextualisation of all data, however this is rarely the case in practice. We see a more explicit, semantically defined linkage between model elements and other project information as being beneficial in helping actors to understand the overall project context within which they work.

We see other problems that render data level integration in the STEP or IFC mould less effective than might otherwise be the case. To understand this position it is necessary to consider the way in which data integration mandates a considerable degree of work up-front. This is required in order to agree upon standards, construct a schema for integration, adapt applications to the standards etc. all before any benefits are realised. These issues become more onerous the larger the scope of agreement one is trying to achieve (inter-organisational, national, international etc.). Finally, for large international standards efforts, agility is something of a problem. Once the standard is agreed, changing it can take a considerable amount of time, which in an age of rapidly evolving business needs can turn a formerly helpful system into a hindrance.

We believe that leveraging ontologies may go some way to help resolve some of the above stated issues. Various definitions of what forms an ontology have been formulated and have evolved over time. A good description of these can be found in Corcho et al., (2003). From the author's perspective, the best definition that capture's the essence of an ontology is the one given by Gruber, (1994): "an ontology is a formal, explicit specification of a shared conceptualization". As elaborated in Studer et al., (1998): "Conceptualization refers to an abstract model of some phenomenon in the world which identifies the relevant concepts of that phenomenon. Explicit means that the types of concepts used and the constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine processable".

The use of an ontology or multiple ontologies of the construction domain could act as a semantic abstraction layer above current standards and models to further integrate project data in a more intelligent fashion. For example, an ontology with appropriate mappings into the underlying data models could be used to provide a more intuitive view of project data for any given actor based on their particular disciplinary concepts and terminology. That same ontology could also provide the view for an actor from a different discipline, based on the relationships explicated within the ontology itself providing links to the appropriate terminology for the same data items. This type of 'translation' function becomes more compelling when used to view initial project briefs or client constraints and later when viewing the rationale for changes as it helps all actors to understand the reasoning involved in a language they can comprehend easily. Indeed Yang and Zhang, (2006) have proposed extensions to the IFCs to map them into ontologies for the construction domain to improve the semantic interoperability of BIM models in just such a way. The mapping of ontology concepts into the current data model specifications would be performed initially in a semi automated fashion, perhaps using tools such as those identified by Amor, (2004) for mapping between the data standards themselves, suitably modified for the task.

With respect to unstructured project information, the use of ontologies in tandem with other techniques drawn from information retrieval/extraction could be used to automatically infer links between the structured and unstructured information and indeed between items of unstructured information, based on the links defined in the ontology. These links lend a greater degree of context to each item relative to the project as a whole. Benefits may also be derived from uncovering previously unseen linkages between various elements of project data using such analysis methods. Kosovac et. al., (2000) and Schere & Schapke, (2005) have done research work in this or closely related areas. Some elements of the authors' own work have developed or used ontologies in ways similar to these. The eCognos project for example, developed and used a construction oriented ontology to augment the services that it offered as part of the collaborative knowledge management environment also developed on the project (Wetherill et al., 2002; Lima et al. 2005). The FUNSIEC project took the eCognos ontology and numerous other European semantic resources, compiling them into an educational 'Experience Centre' and further conducting a feasibility study into the production of what the project termed an 'Open Semantic Infrastructure for the European Construction Sector (OSIECS) (Barresi et al. 2005).

In the following section, we introduce the requirements for such ontologies and provide an illustration of a potential ontology for the sector.

4 THE CONSTRUCTION ONTOLOGY

A critical analysis of the semantic resources available in construction, ranging from taxonomies to thesauri, combined with an understanding of the characteristics of the sector, have helped formulate a set of requirements that ought to be addressed in order to maximize the chances of a wide adoption of any ontology project in the construction sector. These requirements are listed below:

- The ontology should not be developed from scratch but should make as much use as possible of established and recognized semantic resources in the domain.
- The ontology should be built collaboratively in a multi-user environment: the construction sector involves several disciplines and communities of practice that use their own jargon and have specialized information needs.
- There is a need to ensure total lifecycle support, as the information produced by one actor within one discipline should be able to be used by others working in related disciplines.
- The ontology must be developed incrementally involving the end-users. This is important given the multi-disciplinary and multi-project nature of the industry, and the fact that each project is a one-off prototype.
- The ontology should be flexible and comprehensive enough to accommodate different business scenarios used across projects and disciplines.
- The ontology should be user friendly, i.e., easy to use and providing a conceptualization of the discipline / domain being represented that embeds the technical jargon used in the sector.
- The ontology should be a living system and should allow for future expansion.

Given the following factors: (a) the fragmented and discipline-oriented nature of the construction sector; (b) the various interpretations that exist of common concepts by different communities of practice (disciplines); (c) the plethora of semantic resources that exist within each discipline (none of which have reached a consensual agreement); (d) the lifecycle dimension of a construction project with information being produced and updated at different stages of the design and build process with a strong information sharing requirement across organizations and lifecycle stages; a suitable ontology development methodology should accommodate the fact that the ontology should be specific enough to be accepted by practitioners within their own discipline, while providing a generic dimension that would promote communication and knowledge sharing amongst these communities.

Given the above requirements, an ontology is developed, referred to as eCognos (Lima et al. 2005, Rezgui 2007d). The eCognos ontology is structured into a set of discrete, core and discipline-oriented, sub-ontologies. Each sub-ontology features a high cohesion between its internal concepts while ensuring a high degree of interoperability between them. These are organized into a layered architecture (three layers) with, at a high level of abstraction, the core ontology that holds a common conceptualization of the whole construction domain enabled by a set of interrelated generic core concepts forming the seeds of the ontology. These generic concepts enable interoperability between specialized discipline-oriented modules defined at a lower level of abstraction. This middle layer of the architecture provides discipline-oriented conceptualizations of the construction domain. Concepts from these sub-ontologies are linked with the core concepts by generalization / specialization (commonly known as IS-A) relationships. The third and lowest level of the architecture represents all semantic resources currently available, which constitute potential candidates for inclusion into eCognos either at the core or discipline level.

There are a large variety of available semantic resources that can form the basis for building the eCognos core ontology. These range from classification systems to taxonomies. The latter deserve particular attention as argued in Welty and Guarino, (2001). One of the principal roles of taxonomies is to facilitate human understanding, impart structure on an ontology, and promote tenable integration. Furthermore, properly structured taxonomies: (a) help bring substantial order to elements of a model; (b) are particularly useful in presenting limited views of a model for human interpretation; and, (c) play a critical role in reuse and integration tasks. Improperly structured taxonomies have the opposite effect, making models confusing and difficult to reuse or reintegrate (Welty & Guarino 2001). IFCs, being more recent and also the closest taxonomy currently in use in the sector, are therefore the preferred candidate semantic resource that can provide the skeleton on which such a core ontology can be built.

A particular approach is adopted for building and/or expanding the discipline-oriented sub-ontologies. This involves selecting and making use of a large documentary corpus used in the discipline and ideally produced by the end-users. The sub-ontologies are then expanded and built from index terms extracted from commonly used documents using information retrieval techniques.

5 INTEGRATION THROUGH ONTOLOGY-BASED SEMANTIC SERVICES

Given the shortcomings we have identified in the current product data centric approaches to integration and our suggestion that the use of ontologies at this level could go some way towards addressing them, we would further propose that in order to have systems that actors can interact with in a more intuitive way, ontologies have a more roles to play. Here we envisage a number of elementary components, each furnishing a small piece of functionality, usually some discipline specific function, in a fully encapsulated independent fashion. These components, published as Web Services could be further composed into higher-level business process components, again self-contained as per the component based development typical of modern object oriented systems. This model of arbitrary combinations of process components or e-processes as one might call them, allows for greater flexibility in the definition and production of business systems to support construction projects. Ontologies play their role not only at the basic level of a semantic integration layer over the data as detailed previously, but also (a) as a means to describe the concepts and relationships inherent in the processes of construction projects and (b) as a means to articulate at a semantic level the precise nature of an offered service. Working at this higher process oriented level, we begin to see opportunities for resolving some of the lifecycle and context shortcomings of current data models. An ontology of the construction domain will include concepts devoted to the description of the processes involved in construction projects, thus the relationships between the data on the one hand, and the process within which it is used on the other become more explicit. These explicit links between process and data concepts can be used to map out a detailed context for information elements relevant to each actor's role in the project and presented in terms that they would normally use. The existence of a process directly serviced by an information system all of which is ontologically described allows us to create interfaces to the process for individuals based on their role and the specific stage of the process at which they are currently working, which present relevant information in a timely manner again customised to the needs and language of the actor.

The OSMOS, C-Sand, and eCognos projects in which the authors were involved all employed architectures featuring multiple interoperating services to furnish their functionality to varying degrees. The success of these projects demonstrates the utility of the orchestrated service approach whilst eCognos, as previously mentioned, also featured an ontology to augment its services with semantic capabilities. The systems developed under the eCognos and C-Sand projects also featured the ability to consume arbitrary web services for use 'on the fly'. The development of this feature did not however extend to any automated notion of what those arbitrary services 'were' or 'did', which rather limited its usefulness. Thus we believe that extending the work to encompass services semantically described by means of ontologies would allow for a more automated integration and orchestration to take place, particularly when ontologies are also used to map the services to the business process being served.

The technologies required to implement basic process oriented systems already exist or are being developed. Web Services have been established for some years and their popularity among business system implementers continues to grow steadily. The means by which to aggregate a number of Web Services into a larger business process oriented service are provided for in the Business Process Execution Language (BPEL) and the various runtime environments built to action the processes it describes. The BPEL specification defines constructs similar to a simple programming language such as loops, assignments, branches etc, with which to define the flow of calls between a collection of orchestrated services involved in a modelled process. The whole Web Services stack comprises several other standards including those for securing communications between services and clients (WS-Security), standards for transaction demarcation and management (WS-Transaction) etc. One of the more important amongst the various protocols for the future of Web Services is the Universal Description, Discovery and Integration protocol (UDDI), which allows for the publication and discovery of services on the Web. UDDI has a problem in that whilst it is possible to publish a service description and have it searchable by others, it does not make explicit what the service is for in language that a machine can understand. Thus it is that a human must currently decide whether a particular service is suitable for their business' needs by manually examining both the technical and textual descriptions of a service for compatibility. Removing this manual intervention would allow UDDI to be much more useful than it is today and would permit the type of process oriented services we envisage to be assembled in a more automated fashion. It is here that much current research and development work is concentrated under the Semantic Web Services banner. Standards to describe what a service is for and what the various inputs and outputs actually mean in machine interpretable form are being developed with OWL based ontology for Web Services (OWL-S) and the Web Services Modelling Ontology (WSMO). Both of these standards define ontological constructs for describing services and allow external ontologies to be used in the description of service parameters. It is in this role that domain specific ontological concepts such as those defined by the FUNSIEC project (Barresi et al. 2005) or eCognos can be employed to describe services for particular business fields. Together with the lower level Web Services protocols, these ontologies allow for the semi automated composition of aggregate services modelled in line with the business process requirements of specific domains.

In the next section we look at the dynamic nature of construction project processes and the requirements this places on our proposed e-process enabled computing environment.

6 LIFECYCLE DIMENSION AND SUPPORT FOR THE DYNAMIC AND LONG-LASTING NATURE OF E-PROCESSES

The design stage of a project involves interesting examples of long-lasting processes. The multiplicity of circumstances governing the decision making processes inherent in architectural design leave scope for numerous misunderstandings, unforeseen difficulties created by inappropriate or ill-conceived information, changes and decisions which fail to propagate amongst all interested parties. Further, these circumstances are commonly compressed into short timeframes featuring periods of intense activity in which many decisions are made.

The design process is currently supported by a number of software applications, including CAD and related engineering software. It can be modelled as a dynamic, long-lasting, process, and therefore provides an ideal example of an e-Process. However, there exist several limitations of service process approaches that hinder the effective adoption of such a paradigm. Long running cooperative processes are subject to evolutions and changes of differing nature: process model evolution due to change in the environment (change in the law, change in the methodology), process instance evolution (or ad-hoc evolution) due to specific events occurring during a given process execution (delay, newly available or missing resources) or partnership evolution at execution time having an impact on part of the process. These shortcomings require essential advances and improvements, including:

– Tracking of history of changes: change management is an important issue in long lasting processes. When a process model (or an abstract process) is changed, it may be important to migrate running processes to reflect these changes. However, this migration is sometimes only feasible under certain conditions, and must be implemented dynamically.
– Partner change during process execution (dynamic change of partner, with partial fulfilment of choreography): during a long lasting process, a partner may fail to complete a conversation, or even disappear. In this case, a new partner has to be selected, dynamic re-composition has to occur and part of the execution may have to be restarted. It is essential that change of partners be dynamically supported in the context of the executed choreography.
– Partial rollback (check pointing): events such has dynamic change of partners may require a process to be partially rolled back and re-executed with a new partner. This partner may even benefit from the previous partial execution. Partial rollback or compensation may also be triggered by a change in the process. These scenarios are unsupported or ill-supported by the current BPEL specification. Partial rollback will require adapting the Business Activity transaction model to allow a more flexible approach than the simple open nested transactions.
– Process evolution (unpredictable event management, dynamic process evolution): during a long lasting process, events may occur such as unexpected delay or resources evolutions that require more or less important changes in the process. These changes have to be done while ensuring the correctness of the process itself. The kind of changes that have to be tackled concern adding or removing operations in the process, change in the ordering of the steps, changes in the relationships with the partners (policy evolution). Some work regarding dynamic process evolution has been done already in the area of workflow management systems, which would be of benefit if adapted to BPEL processes. Ad hoc changes are required to

ensure the reliability and the validity of the resulting process.

BPEL as it is defined does not support these kinds of process model evolution and even less ad-hoc evolutions. This is a real problem for long running processes as experienced during the design stage of a project where external and internal unexpected events may require adaptation and evolution. It is worth noting the pivotal role of a construction ontology in resolving many of the above limitations, in particular those related to semantic compatibility between services. Since individual web services are created in isolation, their vocabularies are often rife with problems having abbreviations, different formats, or typographical errors. Furthermore, two terms with different spellings may have the same semantic meaning, and thus are inter-changeable. Diverse matching schemes have been developed to address these semantic resolution problems, including in the context of the eContent FUNSIEC project. In general, matching approaches may fall into three categories: (a) Exact match using syntactic equivalence; (b) Approximate match using distance functions (TF-IDF, Jaccard, SoftTF-IDF, Jaro, or Levenstein distance); and (c) Semantic match using ontologies. The latter is the authors' preferred approach as it provides the possibility to reason about web services, and to automate web services tasks, like discovery and composition.

Figure 3 illustrates a comprehensive framework that summarises the above shortcomings and issues identified in the paper, and provides a potential e-Platform solution for the construction industry. This has been inspired from the authors' research. The underlying web-service infrastructure has already been developed as reported by Rezgui (2007b), while some of the suggested services have already been specified and prototyped, including the Ontology service and the Semantic compatibility service. We would also suggest a business model based on the application service provider model for the deployment of the technical solution. Here we envisage three roles as described in Boddy et al (2007)

- Service provider – any organisation having services (specifically web services) that they wish to monetise and offer to third parties for their consumption. Providers register their services with the aggregator for publishing and composition into e-Processes.
- Service aggregator/host – An organisation with responsibility for hosing the infrastructure defined in the middle layer of figure 3 below. The aggregator composes business systems (e-Processes) from the offerings of registered service providers tailored to the requirements of particular projects or organisations (real or virtual) and their business processes.
- Service client – any organisation requiring business system functionality to support their business processes

It is believed that this model will aid construction sector SMEs to adopt technology which may otherwise be out of their reach either technically or financially. We do not however prescribe who may take on the individual roles and indeed envisage that single organisations, particularly large technologically sophisticated ones, might encompass elements of all of them. Centralising infrastructure in this way has the additional benefit of providing a single point of contact for service, support and legal/contractual issues from the point of view of service clients.

7 CONCLUSION

It has been argued that, for successful integration in construction through IT, attention needs to be paid to supporting processes through service oriented approaches; and to improving the human communication aspects and migrating existing information systems through work on ontologies. Rather than attempting to create a vision of common data standards that need to be achieved in whole for benefits to be seen, these approaches provide the potential to realize incremental benefits for the industry through progressive automation of processes, which may be more palatable to the industry. In this scenario, existing work on product models is no longer directed towards the exchange of complete data sets between applications, but provides the cornerstone for defining services that fit into a service-oriented architecture to support construction processes; for defining ontologies that can help to integrate and migrate valuable, existing, unstructured information and knowledge; and for focussing directly on the interactions between different human actors and disciplines in the construction industry.

A technological solution, it has been shown, has to demonstrate capability of supporting the central project (including design) business processes, allow integration of systems and interoperability between disparate applications and enable the management of interactions between individuals and teams, whilst at the same time taking into account the fact that the industry is dominated by SMEs and operates within tight financial margins. The proposed approach will essentially provide a scalable and user friendly environment to support teamwork in the sector by: (a) delivering to clients customised solutions in the form of web services and maintained by a dedicated application service provider; (b) providing an alternative to the traditional licensing model for software provision by introducing a model based on service rental or offered on a pay-per-use basis; (c) providing a change of focus from "point to point" application integration to service collaboration and inter-working; (d) delivering higher-order functionality, composed from elementary services, providing direct support for business processes; (e) providing a ubiquitous dimension to business processes, as services can be invoked anytime, anywhere from a simple web-browser; (f) enabling a single point of contact for service and client support.

The paper argues that ontologies provide a richer conceptualisation of a complex domain such as construction compared to existing product data standards. An ontology should be viewed as a living system. The issue of the existence of a unique ontology for an entire sector remains open. This suggests that while the eCognos Core Ontology forms a robust basis for interoperability across the discipline-oriented ontologies, the latter will need adaptation and refining when deployed into an organization and used on projects. Another issue that can be raised is that related to the adoption of user specific views or perspectives on the global ontology. In fact, in many instances, some actors might be required as part of their job to deal with more than one discipline ontology to conduct a task. This necessitates some flexible mechanisms that can enable the rapid combination of two or more discipline ontologies into a single view / perspective. It is hoped that the paper will stimulate thinking and discussion about the evolution of data products to knowledge-rich ontologies, and their use in the context of construction projects to support seamless e-Processes.

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Workshop: e-NVISION

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

E-procurement future scenario for European construction SMEs

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ABSTRACT: Use of e-Business in construction sector is very limited and the potential of e-Business to increase productivity and efficiency is not exploited. In this context paper is aims to identify most important internal processes of construction small and medium enterprises (SME) and to evaluate possibilities to use information communication technologies to optimise those processes. Methodology used – analysis of current processes of construction in order to find out which are most important for enterprises and define future scenarios of one selected process via story telling. Twelve internal current processes of construction SMEs identified and out of those four most important ones selected according to predefined criteria. Processes selected are: e-Tendering, e-Site, e-Procurement, e-Quality, where "e" stands both for electronic and envisioning. Story telling of e-Procurement scenario defined and functionalities required for this scenario listed.

1 INTRODUCTION

Future business in Europe will be conducted through flexible networks of interdependent organizations. It will be global, open and collaborative, dynamic and adoptive, frictionless and consistent. And it will be electronically supported. There are several organizations that are trying to figure out (and influence also) how the construction sector will evolve in the future. Among them there are government bodies, sectorial consortia, and technological providers. There is a general interest in making good use of advanced information technologies to improve the construction processes. There are two sources of special interest: the construction technological platforms and the European government bodies. The main of them are:

– the European Construction Technology Platform (ECTP) 2030 vision,
– the e-Business W@tch reports in the construction sector,
– the current state in e-Procurement and e-Quality regarding standardization and policies.

The Vision 2030 recommends that the design and construction sector actively engages with a sustainable and competitive Europe. It presents a construction industry that is increasingly client/user-driven, sustainable and knowledge-based, and proposes two interlinked key goals to achieving these: meeting client/user requirements and becoming sustainable.

The main objective of EU funded project e-NVISION (IST-028067, "A New Vision for the participation of European SMEs in the future e-Business scenario") is the development and validation of an innovative e-Business platform enabling Construction SMEs to model and adapt particular business scenarios; to integrate all their enterprise applications and to incorporate legal, economical, social and cultural services, with the final goal of facilitating their participation in the Future European e-Business Scenario. This paper presents part of the work carried out within the project and aims to determine the most important processes of SMEs in construction sector showing ICT implementation possibilities in these processes.

2 METHODOLOGY

e-NVISION project aims to develop new e-Business platform. Fig. 1 provides a high level architecture of the platform that an SME should deploy in order to take part in the envisioning scenarios. It is composed of a central e-Business platform in charge of conducting business with the supply-chain actors, surrounded by two kinds of services: external and integration services. Although these services are not the core business of the company, they are necessary to make the companies' supply chain more dynamic and flexible.

This architecture has served as the basis to establish a working methodology. The research methodology was based on following approach:

– The analysis of current construction processes was based on construction business experts (representatives of construction associations and construction SMEs) interviews for determining main construction business processes.

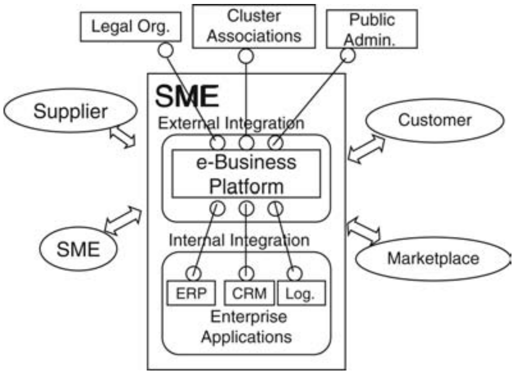

Figure 1. e-Business platform.

- Secondly, the main construction business processes have been selected according to following criteria suggested by experts: scenarios that can be applied in the Construction Sector, providing new interactions between the actors (PMC, Suppliers, etc.); Scenarios that allow SMEs to participate with other roles, those up to now were almost impossible; Scenarios focused on B2B interactions; Scenarios that make it possible to create new services and actors like ICT Suppliers, Financial, Regulation Agents; Scenarios that include Legal/Cultural/Socioeconomic/Quality aspects.
- Thirdly, envisioning future construction business scenarios ideas have been gathered through brainstorming sessions. In addition, desk research has been carried out to guarantee that the work developed was in the line proposed by other construction experts and sources, including e-Business Watch, ECTP and other European Projects related to ICT in Construction (European Commission, 2005a; Wetherill et al. 2002).
- The building of envisioning scenarios have been defined via story telling taking into account all the above and incorporating "higher" level goals to the process definition, such as customer perceived value, whole life performance, legal, social, economic, trust and if possible, sustainability aspects.

Finally, the requirements needed for these scenarios have been defined from two points of view - SMEs involved and external business environment which include public bodies and construction clusters. These requirements have allowed identifying the integration and external services depicted in the initial architecture.

3 CONSTRUCTION IN THE FUTURE

The European Commission, Enterprise Directorate General, launched the e-Business W@tch to monitor the growing maturity of electronic business across different sectors of the economy in the enlarged European Union and in EEA (European Economic Area) countries. According to e-Business Watch (e-Business W@tch, Report 08-I, in terms of ICT uptake and e-Business deployment, the construction sector today is characterised by: highly fragmented ICT usage; a multitude of standards, technical specifications, labels, and certification marks as well as diversity in local, regional and national regulations; a low adoption and integration of relevant ICT in most business processes, especially by SMEs, which are often characterized by communication and knowledge sharing based on personal or telephone contact; many small-sized companies which are typically either organizers of projects and project flows or suppliers to larger project-managing companies, with different ICT requirements.

The construction industry has yet to show the same level of ICT driven improvement of productivity as in other industries. The potential of e-Business to increase productivity and efficiency in the construction sector is far from being exploited. A well-functioning market of ICT vendors and e-Business solutions exists. Barriers for increased uptake of ICT are very much related to lack of resources, insufficient knowledge about ICT costs and benefits, absence of skills, as well as the prevailing traditions and culture in this sector.

Therefore, there is still great potential for further ICT uptake, for example: production planning systems, ERP systems with financial components, inventory management systems, supply chain management (SCM) and mobile solutions. Another conclusion from the report is that business process integration may be a key driver for ICT adoption in the future.

This indicates that it could be cost-effective to launch policy initiatives in order to increase the level of awareness of e-Business applications in the construction sector. In this context, the following three areas of policy actions have been identified as appropriate (European Commission, 2005a):

- Improving ICT skills;
- Increasing the awareness of ICT benefits and potentials;
- Facilitating the process of interoperability.

The new solutions and increased ICT uptake are expected in six areas (European Commission, 2005a):

- Collaborative software, project webs and platforms for cooperation between partners in consortia.
- Mobile solutions to improve coordination, flexibility, and resource management.
- Integrated ERP solutions focusing on the main business processes of project management, risk management and resource management.

– e-Procurement as a way to reduce costs in large project-driven firms (consortia leaders).
– e-SCM (systems for supply chain management) to support internationalisation and industrialisation.
– As reduced margins drive business models to focus on services, industry ERP solutions will include management of services, e.g. facility management. Other construction companies will expand into project development and will look for ICT solutions that support this.

The research carried within e-NVISION project aims at providing insight into some of the above areas: e-Procurement, B2B based ways of collaboration between partners, and services oriented integration in the Construction sector. Analysis of current processes that takes part in the Construction Process was done and the following processes were identified.

– PM-01: Tender and agreement with the General Contractor.
– PM-02: Control of design documentation
– PM-03: Planning and scheduling
– PM-04: Construction coordination
– PM-05: Investor's supervision
– PM-06: Marshalling of machines and equipment deliveries
– PM-07: Organisation of process start-up
– PM-08: Preparing reports
– PM-09: Control of costs and financial settlements
– PM-10: Final acceptance and report
– PM-11: Development and implementation of Quality Assurance Programme
– PM-12: Supervision of safety and health at work matters (e-NVISION project IST-028067, 2007a).

The construction sector is moving from a very traditional sector where the main objective for development was to minimize the construction costs, towards a demand driven sector where other factors, such as, product quality, user requirements or even sustainability are taken into account. The idea behind this evolution is to give priority to sustainability over other industry priorities. Hence, as the construction sector is maturing, the business drivers tend to shift from basic cost, quality and time towards "higher" level goals such as customer perceived value, whole life performance and sustainability.

The criteria used for selecting and defining the business processes have been suggested by construction sector experts (e-NVISION project IST-028067, 2007a):

– Scenarios that can be applied in the Construction Sector, providing new interactions between the actors (PMC, Suppliers, etc.).
– Scenarios that allow SMEs to participate with other roles, those up to now were almost impossible.
– Scenarios focused on B2B interactions.
– Scenarios that make it possible to create new services and actors like ICT Suppliers, Financial, Regulation Agents.
– Scenarios that include Legal/Cultural/Socio-economic/Quality aspects.

Four scenarios have been selected to be envisioned out of twelve because they best fulfil the above criteria (e-NVISION project IST-028067, 2007a):

– PM-01: Tender and agreement with the General Contractor.
– PM-04: Construction coordination.
– PM-06: Marshalling of machines and equipment deliveries.
– PM-11: Development and implementation of Quality Assurance Programme.

In current paper the more detail analysis will be concentrated on PM-06: Marshalling of machines and equipment deliveries or e-Procurement process.

4 E-PROCUREMENT SCENARIO DESCRIPTION

Topic of procurement of construction materials, equipment and services via internet is not very new – quite a few authors (Construction Industry Institute, 1987; Kong et al. 2001; Kong et al. 2004) already analysed this issue. Following are provided findings of authors of paper on this issue from SMEs in Lithuania, Slovenia and Poland (e-NVISION project IST-028067, 2007a).

The procurement process of acquiring products and services for the construction takes into account the Investor requirements specified in an accepted offer that contains all of the technical documentation needed to execute the whole construction process dealing among others with the following aspects:

– *Look for suppliers offering whole products,* like house/part of construction/installations or machinery where supplier itself must get (well procure on his level) all building products/materials to make his product.
– *Look for suppliers offering specific services*, like designers to make plans, engineers to make calculations, solutions, engineers to supervise actions like design, building on site, quality of delivered material, etc.
– *Choose (PMC or Investor) the most appropriate supplier* to buy some building products that construction company (Contractor) will use to build.
– *Choose the most appropriate supplier* to rent some building machinery.

Therefore, in this process will be involved all or part of the following actors, playing different roles depending on the type of situation:

– (General) Contractor,
– Project Management company (PMC);
– Investor,
– Suppliers (SMEs) of building products and services.

Nowadays, it is very difficult for new SMEs (suppliers) to start working with an investor if no previous contacts have taken place between them. Therefore, the SMEs have a very limited market with enormous difficulties to expand. Therefore, it is clear that SMEs need new advertisement ways to expand their trading activity.

On the one hand, the Investor hasn't got easy ways to find new suppliers and usually works with the same ones without benefiting from other suppliers (international market, new start-ups SMEs, etc.). Moreover, investors are under pressure to find ways to cut costs but obtaining, at the same time, good quality products, in order to survive and to sustain their competitive position in their markets.

At the same time, the Construction Sector is moving from a very traditional sector where the main objective for development was to minimize the construction costs towards a demand driven sector where other factors, such as quality of the products, logistics, or the user requirements are taken into account.

Therefore, the new and original approach to this construction e-Procurement process will be focus on the discovery, evaluation and selection of the most appropriate suppliers for an Investor or PMC.

It is foreseen that two main sub-steps will be most important for e-Procurement process, firstly a *selection of potential suppliers* will be done based on supplier and offering characteristics, that is, taken into account the already explained Company Ontology and Product Service Ontology (see e-NVISION project IST-028067, 2007a) and secondly selection will be checked by an *Analysis of Quotation & Selection of Suppliers*, using for its reasoning the Quotation Order Ontology.

Further here all steps of this process are described in detail.

1. *Schedule deliveries*. Project Management Company or other entity (Contractor) that needs to buy products/services (further in this article – *PMC*) prepares a list of products / services required for implementation of project.
2. *Select Suppliers*. In accordance with list of products/services PMC and Investor selects appropriate suppliers/providers. The key idea of the innovative scenario is the development of an effective and rational supplier selection model where the participation of bigger number of SMEs (suppliers) will be promoted comparing to what it is now in practice. To do so, this step is decomposed in sub-steps in order to *formally* add the technological knowledge necessary to enrich this process.

– *Search in Internal Database for Potential Suppliers*.
Depending on positive or negative previous experience, PMC divides its suppliers into two groups: "white list" (preferable suppliers) and "black list" (suppliers preferable not to work with). Suppliers might be on list depending on recommendations of other companies PMC trusts in. This list together with some additions from Investor compiles initial list of suppliers.
Firstly, the PMC goes to the "white list" to look for the appropriate supplier to provide him the required products and services. That list of suppliers will contain valuable information from *previous works* and information of the *supplier activities*, types of products, sourcing strategy, etc. in order to make a proper search.
This internal database will be mapped in terms of the Company and Product Service Ontology to have a more enriched reasoning to look for suppliers.
Depending on how many results appeared afterwards PMC searches externally for other possible suppliers (if there were no suppliers of item found and/or were found not enough of them) or selects potential suppliers (if enough of suppliers were found in initial list).
– *Search externally*.
If there were no (or not enough) possible suppliers, PMC searches for them externally.
To carry this out PMC searches on a registry
where the suppliers (SMEs) that belong to the e-NVISION platform have their products and activities mapped in terms of the e-NVISON domain Ontologies. (Note that PMC could go back to include the "Black list" suppliers if no other choice).
– *Select Potential Suppliers*.
At this stage PMC has a list of possible suppliers to select from. There may be *negative criteria* to remove suppliers from that list, or *positive criteria* to put those suppliers in order according with those specific criteria (Sonmat 2006).
– *Prepare Final list of Potential Suppliers*.
– After selection of potential suppliers, list of them is prepared. It is used in next step of e-Procurement process to send quotation inquires out.

3. *Prepare and send Quotation Inquires*. After selection of potential suppliers, Quotation Inquires are prepared and sent to list of selected suppliers.

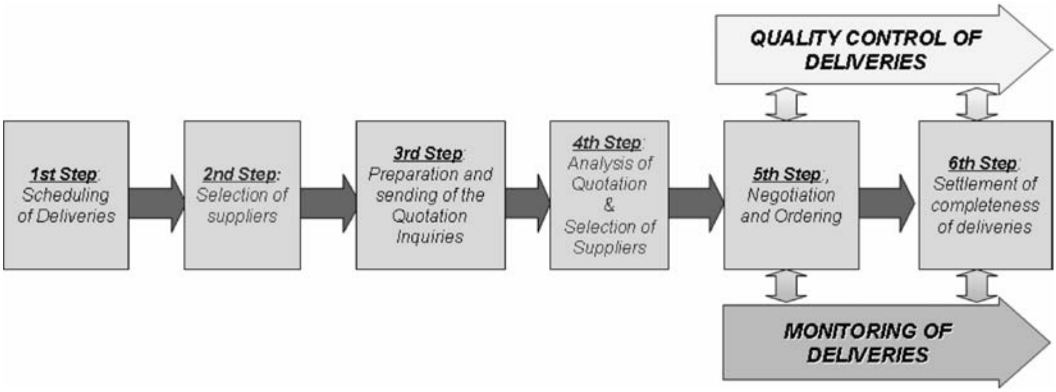

Figure 2. Procurement process.

List of products/services, preferable payment and delivery conditions, deadline of quotation inquire and other information is indicated in quotation inquire. After sending of it, PMC waits for answers.

4. *Analyze Quotation & Select Suppliers*. If any offers are received PMC analyses them and decides upon final list of suppliers to proceed with.

   Decomposition of sub process of analysis of quotation and selection of suppliers is described below.

 – *Receive Offers*.
   Company receives offers from suppliers. These offers might be sent not only from those suppliers, to whom Quotation inquires were sent as SMEs might look for customers themselves and if they got to know somehow about project they might try luck.
 – *Rank Offers regarding most important criteria (1 to n)*.
   As PMC needs to know which of offers received best fits him, so they are ranked regarding criteria most important to PMC. Sometimes one criteria is prevailing, sometimes the other; a compound criteria can be implemented. During analysis of the offer(s) some variations must be considered: is offer with exact items, are quantities as requested or in general which offer (provider) is closest to the request also checking other limits.
   Choose 1 or few Offers best fitting to Criteria.
   After ranking of offers PMC decides which of offers best fits its' needs.

5. *Negotiate and Order*. Afterwards, the PMC and the Investor carries out commercial negotiations with the chosen suppliers and places orders. Order represents all conditions (certain products, quantities, prices, payment, delivery and other conditions) upon which supplier and PMC agreed during negotiation.
6. *Settle completeness of deliveries*. Before settlement of bills the deliveries to the building site or warehouse must be checked if they had been executed as planed (also checking quality certificates, quantity and time of delivery).

5 REQUIREMENTS FOR E-NVISION PLATFORM FOR IMPLEMENTING E-PROCUREMENT SCENARIO

A set of requirements have to be fulfilled so that described envisioning scenario can take place. Some of them describe what the SME must accomplish, the processes that organization must follow or constraints that they must obey. Nevertheless, there are other requirements that are out of the scope of SMEs and depend on public organizations, governments, ICT providers or standardisation bodies.

In the e-NVISION project considered requirements are grouped into six categories:

1. *Data model* is a structured representation of all the data elements and their relationships related with a specific business domain or application. Data models can be expressed in terms of databases, taxonomies, glossaries, dictionaries or in a more enriched way using ontologies. Data models needed for the envisioning scenarios are: tender model, company model, product/service/equipment models, scheduling model, construction work model, quotation/order model, quality model, project model and competences model.
2. *Externalservices* are semantic web services offered by external agents or third parties (e.g. trust and legal agents, agents for the prequalification of SMEs, insurance company) or by the e-NVISION platform (e.g. tender configurator, procurement configurator, supplier discovery service and service locator and registry).

3. *Integration services* integrate the innovative e-Business platform with the internal enterprise applications (e.g. CRM, ERP, companies' databases, document/content management, logistics, quality management) following a semantic service-oriented architecture. Other integration services offered by the e-NVISION platform are the scheduling service and the agent for the analysis of quotations.
4. *Organisational requirements* are those changes that the SME has to introduce in its organization, managing team building and working practices (including training for efficient use of electronic tools) in order to make e-Business.
5. *Socio-cultural requirements* are any cultural or socioeconomic change that has to be promoted by Public Administrations to allow a bigger participation of SMEs in envisioning e-Business scenarios (e.g. more transparency when bidding for a contract, education to increase trust in electronic ways of conducting business, e-Business technology adoption by Public Administrations).
6. *Infrastructure requirements* comprise the requirements set by the platform regarding hardware or software components (e.g. 24/7 accessibility and high-speed Internet connection, desktop computer or portable device, digital registration, identification and signature).

6 REQUIRED FUNCTIONALITIES FOR E-PROCUREMENT SCENARIO

Below we describe how the system should work ie. 'functional requirements'. Some of the functional requirements identified are direct legal requirements, while others are functional prerequisites for implementing those legal requirements in a fully integrated system. The functional requirements for the e-nvisioning scenarios follow the guidelines of the report "Functional Requirements for Conducting Electronic Public Procurement Under the EU Framework" produced by European Dynamics S.A. on behalf of the European Commission (2005b).

The e-Procurement scenario focuses the envisioning efforts mainly on two of these tasks:

1. *Selection of suppliers*. This task would be performed using "Procurement Configurator" external service (e-NVISION project IST-028067, 2007b). The Procurement Configurator external service provides means to configure the list of potential suppliers that can provide a certain schedule of deliveries. This schedule of deliveries consists of a list of products, materials, machinery and equipment identified by a standard classification system. Examples of possible classification systems are CPV (Common Procurement Vocabulary), UNICLASS, OMNICLASS, etc. During the test cases, the CPV classification system will be used. However, the e-NVISION ontology and the Procurement Configurator are flexible enough to allow other classification systems. The Procurement Configurator service takes the list of products, materials, machinery and equipment needed from the schedule of deliveries and matches them with those offered by the companies. The configurator will provide different possible configurations of companies that can provide the schedule of deliveries ranked according to the criteria defined by the user. The user can define 2 types of criteria: exclusion criteria and ranking criteria. By exclusion criteria we mean all criteria that must be fulfilled in order to provide a valid configuration. Examples of exclusion criteria are:

– *Country or region exclusion criteria*: Only companies of the specified country or region will be selected. ISO 3166-1 codes will be used for countries and ISO 3166-2 codes will be used for regions because ISO codes are considered as standard.
– *Maximum price exclusion criteria*: The user can define the maximum price of the schedule of deliveries. A configuration of companies will be a possible solution only if the sum of the prices of all the items that make the schedule is lower or equal to the specified maximum price.
– *Minimum price exclusion criteria*: The user can define the minimum price of the schedule of deliveries. A configuration of companies will be a possible solution only if the sum of the prices of all the items that make the schedule is bigger or equal to the specified minimum price.
– *Maximum number of companies exclusion criteria*: This is the maximum number of companies that can make a valid configuration.
– *Minimum number of companies exclusion criteria*: This is the minimum number of companies that can make a valid configuration.
– Ranking criteria are criteria that can be used to rank the different possible configurations of companies that can provide the schedule of deliveries. The user will only be able to enter one ranking criteria but as many exclusion criteria as needed. Examples of ranking criteria are:
– *Price ranking criteria*: The list of possible configurations will be ordered according to the total price of the schedule of deliveries, being the configuration with the lowest price the first in this list.
– *Number of companies ranking criteria*: The list of possible configurations will be ordered according to the total number of companies that make the configurations, being the configuration with the minimum number the first in this list.

2. *Analysis of Quotation*. This task would be performed using "Agent for Analysis of Quotations" integration service (e-NVISION project IST-028067, 2007c).
   The agent for quotation analysis integration service provides the means to rank quotations by criteria. To do this analysis the Quotation/Order Model included in the e-NVISION ontology will be used. The main functions of the Quotation Analysis Agent are:

   – The agent for the analysis of quotation integration service is designed to choose the best quotations (proposals) out of those sent to the company.
   – The service is supposed to rank quotations (proposals) so that the user of the service can see which quotation is best.
   – For ranking quotations, the criteria defined by the user will be used.
   – There could be the possibility of giving weights to the criteria specified by the user.
   – Possible ranking criteria are:
   – price (or ratio price/performance);
   – performance (product/service properties – at least they must match requested, but if they are better, maybe they score better – depends on Investor wishes);
   – quality (CE mark, other certificates/awards, good experience from previous projects);
   – experience from previous collaboration (like issues of quality of products/service, delivery, etc.);
   – delivery in time frame;
   – geographic location (proximity);
   – competence (quality, reliability) of supplier;
   – special offers from suppliers/providers.

For this scenario the following functionalities are required:

– *Registration mechanism (with user authorization and authentication)*: This functional requirement allows users to register to e-NVISION services. The registration process must ensure the confidential transfer and storage of all personal information of users. Furthermore, mechanisms may be put in place for the validation of the information provided by new users of the system. Hence, the registration process may be performed in two phases. One phase can allow new users to apply for registration to the system, and another phase can allow authorised personnel to validate the submitted information and approve or reject a registration application.
  This functional requirement relates to the ability of the e-NVISION system to store personal information of its registered users and companies. Users can update their personal information if required. The information will be stored in terms of the data models previously identified.
  Moreover, user profiling can allow users to setup their preferences when using the system, in terms of how data is searched, displayed, etc. Depending on the user rights for each user, the system can control which activities a user can perform, as well as, what data a user should have access to.
– *Search Suppliers mechanism*: to any registered party a system may provide that it can search through all registered suppliers and locate ones that provide a certain product, material, machinery or equipment.
– *Evaluate Suppliers according to criteria*: system may provide a mechanism to evaluate suppliers according to specified criteria. This will facilitate the selection of suppliers.
– *Request for Quotation*: system may provide a mechanism to request a quotation to a supplier, i.e. to send electronically a quotation inquiry.
– *Evaluate Quotations according to criteria*: system may provide a mechanism to evaluate quotations according to specified criteria.
– *Request for Order*: system may provide a mechanism to request an order to a supplier, i.e. to send electronically an order.
– *Accept/Reject Order*: The e-NVISION system may provide a mechanism to accept or reject an order.

7 CONCLUSIONS

It is a fact that the future business scenario will be global, open, collaborative, dynamic, adaptive, frictionless and consistent. The question is whether the SMEs are ready to participate in it or not. Therefore, more than as an opportunity, SMEs have to see it as a necessity, as a way of survival. Public Administrations have the responsibility to provide SMEs with all the mechanisms and tools needed to survive in this globalised world. But at the end SMEs will have to make an effort adopting organisational changes and acquiring skills and capacities needed to participate in the future e-Business scenarios.

Envisioning e-Procurement scenario allows the participation of the biggest number of SMEs (suppliers) and more complicated ways of collaboration among them. Therefore this envisioning scenario matches in an appropriate an optimal way the demand (Investor needs) and the offer (supplier services) deploying the requested e-marketplace in the envisioning ideas.

In future e-marketplace the products and services will be published allowing different ways of interdependences between them to provide the best matching mechanism for a specific market need.

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e-NVISION e-Business ontology for the construction sector

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ABSTRACT: One of the main results of the e-NVISION project (http://www.e-nvision.org) is a vertical e-Business Solution for the Construction Sector. This solution provides the means to participate in the future e-Business scenarios. In order to make business and to implement the e-nvisioning scenarios, it is necessary to share information in a common vocabulary of terms and relations. To this end, the e-NVISION ontology has been defined. Due to the fact that ontologies are used with different purposes according to their areas of application, it is normal that models that represent the same domain differ from one and other. Up to now, different construction ontologies have been defined for different purposes. Our goal has been to develop a construction e-Business ontology covering the concepts and relations needed to implement the following four e-Business scenarios for the construction sector: e-Tendering, e-Procurement, e-Site and e-Quality. This ontology tries to re-use existing classification systems in order to develop a compatible model that may contribute to standards.

1 INTRODUCTION

One of the main results of the e-NVISION project (http://www.e-nvision.org) is a vertical e-Business Solution for the Construction Sector. This solution provides the means to participate in the future e-Business scenarios of four core construction processes: e-Tendering, e-Procurement, e-Site and e-Quality (Angulo et al. 2006, Bilbao et al. 2007, e-NVISION 2007a). One of the main barriers to collaboration is the difficulty to exchange information in a common vocabulary and with the intended precise meaning. This is even more important when exchanging information in electronic format, as is the case of e-Business transactions, or in a domain where great number of actors are involved, as is the case of the construction sector.

In a construction project, different companies and people have to work together: main constructor, subcontractors, designers, investors, material providers, suppliers of machinery, etc. All these actors need to share and reuse knowledge in computational form not only when making business to business transactions but also in their internal daily processes. The interoperability among the e-business solutions is the key issue for the implementation of seamless e-business scenarios. The European Interoperability Framework (EIF 2004) defines three key layers of interoperability:

– Organisational interoperability is about being able to identify the players and organisational processes involved in the e-Business scenario and achieving agreement among them on how to structure their interactions, i.e. defining their "business interfaces".
– Technical interoperability is about knitting together IT systems and software, and defining and using open interfaces, standards and protocols in order to build reliable, effective and efficient information systems.
– Semantic interoperability is about ensuring that the meaning of the information exchanged is not lost in the process, and that it is retained and understood by the people, applications and institutions involved.

This paper deals with the Semantic Interoperability layer and the need to share information in a common vocabulary of terms and relations. To this end, the e-NVISION ontology has been defined (e-NVISION 2008a). Our goal has been to develop a construction e-Business ontology covering the concepts and relations needed to implement the following four e-Business scenarios for the construction sector:

– The e-Tendering scenario tries to enhance SMEs participation in calls for tenders (e.g. as a group of SMEs or as a Virtual Enterprise) on equal footing compared to bigger tenderers, reducing the work needed to analyse paper propositions, in an open and transparent world-wide electronic market, with mechanisms to look for partners internationally, and supported by trust and quality external organizations.
– The e-Site scenario will improve the companies' coordination in the construction time, reporting in an automatic way any change or incident at the

construction site to the interested partners so that they can react as soon as possible.

- The e-Procurement scenario looks for potential providers both internally and externally thanks to an effective and rational supplier selection model that allows discovering, evaluating and finally selecting the list of providers of a certain schedule of deliveries.
- The e-Quality system is centred in two main issues: the documents and their management, and organising all the information and data to perform the tasks according to the work specification and in compliance with the standards.

Instead of defining the ontology from scratch, e-NVISION has based its research on the most relevant currently available national and international knowledge sources, i.e. taxonomies, ontologies and construction models, in order to develop the e-NVISION ontology. This ontology tries to reuse existing classification systems in order to develop a compatible model that may contribute to standards.

2 METHODOLOGY

Ontologies facilitate communication as they provide the terms, their meaning, their relations and constraints which model a certain domain. Due to the fact that ontologies and the related resources are used with different purposes according to their areas of application, it is normal that models that represent the same domain, in this case the construction sector, differ from one and other.

The area of application of the domain varies the perspective of the ontology which determines what aspects of a domain are described. Besides, the extent of the model, i.e. the things at the periphery of the domain that are included or not included, and the granularity of the model, i.e. the level of detail in which a domain is described, also depend on the future use of the ontology. We cannot say that one ontology is better or more appropriate than another for a certain domain without considering its future use.

Up to now, different construction ontologies have been defined for different purposes. For instance, the bcBuildingDefinitions taxonomy developed by the eConstruct project (www.bcxml.org) was mainly used to support the creation, publication and use of electronic catalogues of construction products - the electronic commerce, to some extent. The e-COGNOS Ontology (www.e-cognos.org) has been developed with one single purpose: support the adoption of Knowledge Management practices in the BC sector. However, there is no single construction ontology that gathers all the concepts that are needed to implement e-Business scenarios in the construction sector.

The opinion supported by the authors of the CEN publication CWA 15142 “European eConstruction Ontology (EeO)” is that a unique ontology for the construction sector will never exist.

In accordance to this opinion, the construction e-Business ontology described in this paper does not try to replace existing construction ontologies and should not be considered as the unique ontology for the construction sector. The e-NVISION ontology covers the construction domain under an e-Business perspective. The extent and the granularity of the model have been determined by the detail needed for four core construction e-Business scenarios: e-Tendering, e-Procurement, e-Site and e-Quality.

The e-Business ontology for European Construction SMEs Collaboration has been implemented using OWL (Web Ontology Language). The Ontology covers e-Business generic concepts, applicable to any sector. Regarding e-Business, although many definitions of this term exist, we will use the definition that appears in the European e-Business Report (2006/07 edition). According to this report the term “e-Business” will be used “in the broad sense, relating both to external and to company-internal processes. This includes external communication and transaction functions, but also ICT-supported flows of information within the company, for example, between departments and subsidiaries”. Taking into account this definition, in order to define an e-Business scenario it is necessary to define the actors involved in the scenario, including among others companies, departments, subsidiaries, virtual enterprises, individuals and so on. It is also necessary to define the role of each actor, like buyer, seller, subcontractor and so on.

The generic concepts and relations modeled in this ontology have been grouped by several categories: Actor Domain, Business Domain, Item, Item Classification and User Criteria.

Besides, a domain has been defined to include the specific concepts needed for each of the e-Business scenarios: Tender Domain, Procurement Domain, Construction Site Domain and Quality Domain. This way, the ontology can be easily extended as new e-Business scenarios are considered.

It is not the intention of the authors to consider this e-Business ontology as “THE CONSTRUCTION ONTOLOGY”. The goal has been to develop a construction e-Business ontology covering the concepts and relations needed to implement four core e-Business scenarios for the construction sector: e-Tendering, e-Procurement, e-Site and e-Quality.

3 EXTERNAL SOURCES REUSE

In order to develop the e-Business ontology for European Construction SMEs Collaboration or e-NVISION ontology, research was based on the most relevant currently available national and international knowledge sources, i.e. taxonomies, ontologies and construction models. This ontology re-uses where possible existing classification systems in order to develop a compatible model that may contribute to standards.

3.1 *Construction projects and initiatives*

Firstly, several construction projects and initiatives targeting semantic resources development were analysed. The most relevant for e-NVISION were:

- The bcBuildingDefinitions Taxonomy developed by the eConstruct project;
- The e-COGNOS Ontology which supports the adoption of Knowledge Management practices in the BC sector;
- ISO 12006 "Building construction", an international standard for organising the information about construction works. It defines a schema for a taxonomy model.
- The IFC (Industry Foundation Classes) Model which has been developed to enable the exchange and sharing of Building Information Models to increase the productiveness of design, construction, and maintenance operations within the life cycle of buildings.

3.2 *Construction classification systems*

Secondly, the main construction classification systems, taxonomies and vocabularies were looked into: The British Standard 6100 (BS6100) provides a glossary of the terminology used in the construction sector; Uniclass (UK) focuses on both architectural and civil engineering works; OmniClass (North America) is a strategy for classifying the entire built environment; Lexicon (Netherlands) is an implementation of ISO 12006-3; BARBi (Norway) tries to establish a reference data library for the building and construction industry; the French Standard Dictionary for Construction (SDC) intends to become the dictionary of reference of the construction products; the European Common Procurement Vocabulary (CPV) establishes a single classification system for public procurement aimed at standardizing the references used by contracting authorities and entities to describe the subject of procurement contracts.

The main drawback of all these glossaries and classification systems (except for CPV) is that they are focused on the construction terms used in specific countries. Therefore, they are not accepted across Europe.

3.3 *e-Business ontologies*

Finally, research was focused on existing ontologies implemented for other sectors that cover any of the concepts of the e-Business scenarios developed in e-NVISION:

- The Enterprise Ontology (M. Uschold et al. 1998) is a collection of terms and definitions relevant to business enterprises. It contains most or all of the general terms relating to an enterprise, but it needs to be extended to include more detail specific to the construction sector. The e-NVISION ontology has a narrower extent but introduces new concepts such as Virtual Enterprise and groups items not only as products but distinguishes among products, materials, equipment, services and software.
- The Tendering Ontology (A. Kayed et al. 2000) tries to define the ontological structures needed for a tendering process independent from the sector where it will be used. The ontology contains abstract concepts that form the primitives to construct a tender or a bid. Three of the most important conceptual structures of this ontology are the tendering invitation structure (TIS), the sellers' profile structure (SPS) and the buyers' structure. The e-NVISION ontology covers the scope of the tendering ontology with concepts like Tender, Company, Person, Role, etc and allows having groups of SMEs (i.e. Virtual Enterprise) bidding for a tender and not only a company on its own. The information stored in the TIS concept is stored in the e-NVISION ontology in the tender concept. The tender concept also has information about the location of the tender, the services required for the tender, due date, the official announcement, etc.
- The Scheduling Ontology. Nowadays, SMEs have to use different and incompatible scheduling systems depending on the construction project. The aim is to provide a standardized electronic description of all the scheduling information that will allow interchanging it among project partners no matter the internal scheduling system they use. Two models have been consulted for the development of the scheduling ontology: Task Ontology for scheduling applications (Rajpathak et al. 2001) and CMU Scheduling Ontology(Smith & Becker 1997). The e-NVISION ontology adds the concept Production Activity Task to define the minimum element/entity of the schedule affected by an unexpected event during construction works. Its hasAsignedActor property is used to store the affected actors (companies or individuals) that have to be notified about the event. Besides, some construction specific properties have been added: requiresDocument, requiresForecastCondition, requiresLegalAuthorization and requiresProjectManagementAcknowledge.
- The e-Procurement ontology (Zhao & Lvdahl 2003) was created in order to explore the roles of SOAP (Simple Object Access Protocol) in Semantic Web Services in the domain of e- Procurement. The aim

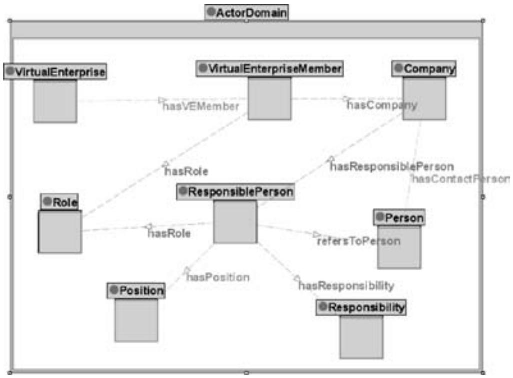

Figure 1. Actor Domain concepts and relations.

of the e-Procurement ontology is not to have a useful ontology but to demonstrate how existing industry standards could be reused to create one, so this ontology is not complete and covers quite small amount of concepts needed for e-Procurement of any industry or for the e-NVISION platform.

4 E-NVISION E-BUSINESS ONTOLOGY: GENERIC CONCEPTS

4.1 *Actor Domain*

The Actor Domain concept groups the classes that contain information related to business actors, i.e., someone or something, outside the business that interacts with the business. This actor can be either a person or a company or a group of enterprises (virtual enterprise). It also includes the concepts related to responsibilities and roles. Figure 1 shows the main concepts and relations under the Actor domain.

The Person class represents an employee of a company or independent skilled people (e.g. a company may prefer to use services of an independent designer or advisor on something). Each individual is related to a full name, contact information, certain skills, formal position taken by the person in the company (i.e. manager, administrator, etc.), role (i.e. general designer, subcontractor, supplier, site manager, supervisor, etc.) and responsibilities that the person can have in the company or in the construction works (i.e. responsible for tender analysis, for quality issues, for contracts, for suppliers, etc.).

The Company concept stores among others the trading and registered name of the company, its VAT number, number of employees, contact information, address, the items (product, service or equipment) demanded or offered by the company, its experience and trust information.

The Virtual Enterprise is linked to different companies that can play the role of partner or subcontractor or general contractor There are different alternatives when an SME participates and bids for a tender. According to these alternatives, the business processes can be divided into four categories:

1 from the point of view of an SME being the General Contractor
2 from the point of view of an SME participating as a partner in the Virtual Enterprise
3 from the point of view of an SME participating as a subcontractor
4 from the point of view of an SME participating in a Virtual Enterprise where there are partners and subcontractors

The Role concept represents the different roles that a person or company can play: PMC, general designer, subcontractor, partner, supplier, site manager, supervisor, quality manager, auditor, etc. A company cannot be assigned roles directly. It always has to be done through a person using the responsible person concept or using the virtual enterprise member concept.

4.2 *Business Domain*

Business Domain represents a structured information schema definition used in business transactions. It is equivalent to the Document used in UBL. However, in the e-NVISION ontology the concept Document represents a physical file as this is the term used by the end users of the ontology, that is, the construction sector workers

The main subclasses are: tender, project, request for quotation, quotation, order and schedule of deliveries.

Up to now there did not exist a standardized description of all the information related with a tender. To solve this problem, new data models (e-NVISION 2007b) have been defined. The aim of the tender concept is to provide a standardized description of all the information related with a tender that will enable automatic tender processing of the type of tender, works to be performed, skills required, documentation to be provided, etc. This way, SMEs will reduce time and human resources when analysing tender calls.

The project class represents the proposal presented by a company or virtual enterprise when bidding for a contract in response to a tender call.

The request for quotation is sent by a buyer company to different supplier companies for the purchase of equipment, products, materials or/and machinery. In response, the supplier company sends a quotation to the buyer company. If accepted, the buyer company will send an order to the supplier company.

A schedule of deliveries consists of a list of products, materials, machinery and equipment identified by a standard classification system.

4.3 *Item*

Product modeling is a key issue when defining an e-Business application.

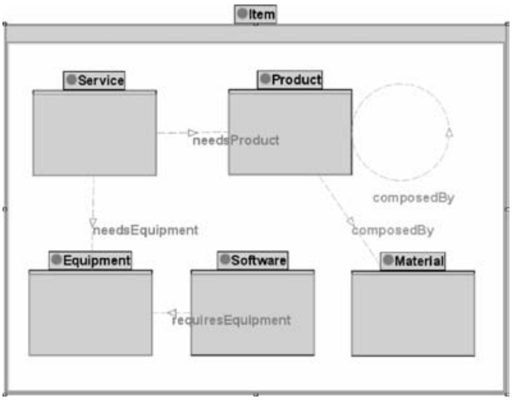

Figure 2. Item main concepts and relations.

We understand product modelling as the representation of a product in terms of parameters that reflect its descriptive and performance characteristics. Descriptive parameters, such as geometry, color, etc., are defined herein as those controlled by the decision maker. Performance parameters, such as comfort levels, energy requirements, etc., are defined as those that the decision maker uses to judge the appropriateness of the product.

In the construction sector the word "product" is used in a specific way. Because of that the e-NVISION ontology defines the concept "Item" to represent the generic concept of product, leaving the word "product" to represent the construction particular meaning.

"Item" conceptualizes the possible offerings of a specific company to the external world (i.e. general product). Item groups the objects: equipment, product, material, service and software. Figure 2 shows the "Item" main concepts and relations.

Equipment is any tool, device or machine needed to accomplish a task or activity of the construction works.

By product we mean anything tangible (physical) that can be offered to a market that might satisfy a want or need. A product is similar to goods, physical objects that are available in the marketplace.

By service we mean anything intangible (non-physical or non-material) that can be offered to a market that might satisfy a want or need. For example, plumbing, electricity, consultancy, etc.

Material is any simple product used in the process of construction (sand, brick, etc.).

Software represents any software which is currently used on the site or related to the process of an activity on the site.

4.4 *Item classification*

Item Classification groups the different classifications of construction products, materials, services, equipment and machinery. One item classification included in the ontology is CPV (Common Procurement Vocabulary) which establishes a single classification system for public procurement aimed at standardising the references used by contracting authorities and entities to describe the subject of procurement contracts. As CPV is officially used in Europe, it can not be "not accepted" by the industry because of its application in TED and public tendering and it is related to other standardised (but old-tech) classification of products, buildings, etc.

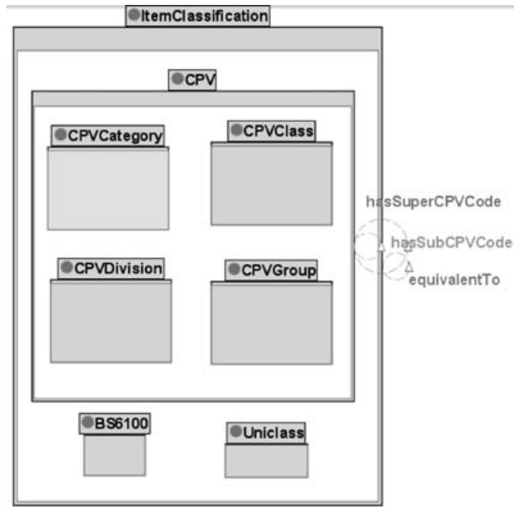

Figure 3. Item Classification: CPV Detail.

With regard to construction classification systems, e-NVISION ontology's main advantage is that it is flexible enough to use any classification system. Moreover, it does not restrict the number of classification systems to use.

The Item Classification class can have as many subclasses as existing construction classification systems. This concept has the object property equivalent To that allows mapping of equivalent items between two classification systems. For example, the item with code 28814000-1 of the Common Procurement Vocabulary classification is described as "concrete" and is equivalent to the item in Uniclass classification with code P22.

In current systems, if Company A registers as able to provide item 28814000-1 of CPV but a tender searches for companies that can provide item P22 of Uniclass classification, then Company A will never be notified of this business opportunity. This obliges SMEs to register and have knowledge of the different construction classification systems. The e-NVISION system does not have this limitation and increases the business opportunities of SMEs as it is flexible enough to use any classification system.

CPV codes are defined for every sector, not only for construction. Therefore, regarding the Item classification, the eNVISION ontology is suitable for every sector without any extension.

4.5 *User Criteria*

User Criteria groups the different criteria that a user can define when making decisions in e-Business scenarios, e.g. selecting the most suitable companies or suppliers to work with, analysing quotations, etc. Generally speaking, criteria are used to filter and rank a set of possible candidate solutions when looking for products, suppliers, subcontractors, quotations and so on.

There are 2 types of criteria: exclusion criteria and ranking criteria. By exclusion criteria we mean all criteria that must be fulfilled in order to provide a valid candidate solution. Ranking criteria are criteria that can be used to rank the different possible solutions.

5 E-NVISION E-BUSINESS ONTOLOGY: SCENARIO RELATED DOMAINS

Besides the generic eBusiness concepts, in the e-NVISION ontology a specific domain has been defined to include the specific concepts needed for each of the e-Business scenarios: Tender Domain, Procurement Domain, Construction Site Domain and Quality Domain. This way, the ontology can be easily extended as new e-Business scenarios are considered.

The next sections present those four domains, including a brief description of the envisioning scenarios defined.

5.1 *Tender Domain*

5.1.1 *e-Tender scenario description*

Tender Domain groups the terms related with the participation in calls for tenders. The complete Electronic Tendering process is divided into five phases that cover different processes: bidding; legal documentation classification; opening of proposals; reckless drop-off presumption; award and contract formalization.

The e-Tendering scenario focuses the envisioning efforts mainly on three of the processes of the bidding phase that are: create new tender call; send tender call notification and make consortium. This is due to the fact that other phases are already being covered by local governments' applications. Besides, this scenario addresses two of the main concerns of the government bodies and institutions which are to encourage more SMEs to respond to tender notices as well as to ensure transparency in public processes.

5.1.2 *Tender Domain concepts*

The tender concept (the tender model) has been included in the Business Domain as part of the generic business concepts, useful for any business sector.

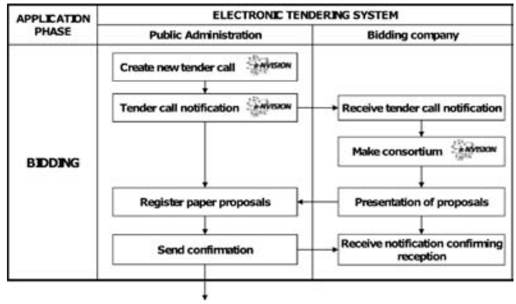

Figure 4. Bidding phase of the e-Tendering process.

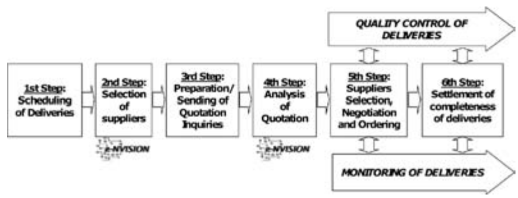

Figure 5. Phases of the procurement process.

The e-Tendering scenario third "make consortium" needs two more concepts that have been included in the Tender Domain. Those two main classes are TenderConfiguratorResult and TenderConfigurator ResultSet.

- TenderConfiguratorResult represents each of the results of the tender configurator. It stores a CPV code, a skilled company for this CPV Code, and a ranking position set for this couple (this information is calculated only if a ranking criterion has been entered).
- TenderConfiguratorResultSet represents a set of possible configurations of virtual enterprises that can bid for a given tender. The set of results are instances of Tender Configurator Result.

5.2 *Procurement Domain*

5.2.1 *e-Procurement scenario description*

The procurement process consists in the acquisition of products or services according to a set of investor's requirements. Figure 5 shows the procurement phases.

The e-Procurement scenario defines a semantically enriched effective and rational supplier selection model to discover, evaluate and select potential and final suppliers. This model represents the knowledge base of a procurement configuration service that figures out the most appropriate group of suppliers.

The search for suppliers can be done both internally, depending on previous experiences of the PMC, and externally via a semantic procurement configuration service. In the first case, the PMC manages two kinds of lists: a "white list" with preferable suppliers and a "black list" containing non trusted suppliers. Besides, both lists store valuable information from previous works and information of the supplier activities, types of products, sourcing strategy, etc. in terms of the data models defined.

To evaluate the suppliers and make a final selection, other criteria additionally to price are taken into account, e.g. quality, special offers, geographic location, ratio of price/performance or previous collaboration experience.

Finally, a quotation analysis of the previously selected suppliers is done. All offers are mapped in terms of the quotation/order data model and ranked regarding the criteria chosen by the PMC.

5.2.2 *Procurement Domain concepts*

Procurement Domain groups the classes related with the e-Procurement scenario. It includes among others:

- delivery conditions (address where items should/will be delivered, delivery period or time, company responsible for the delivery of items)
- list of items requested by the buyer company in the Request for Quotation with their quantity and description
- payment conditions (payment deadline, type of payment e.g. bank transfer, cash, checks or credit card, the way of payment e.g. paid after completed fulfillment, paid after every step of fulfillment or part paid in advance rest after delivery of items)
- price (money amount plus currency e.g. 300 euros)
- pricing policy (per item e.g. price for 1 brick, per package e.g. price for 1 sack of gypsum, per unit of measure e.g. price for 1 liter of paint, result of negotiation if the price set for the item depends on negotiation.

5.3 *Construction site Domain*

5.3.1 *e-Site scenario description*

Nowadays, when an event occurs at the construction site (e.g. a delay or a design change), it is very difficult to inform the interested parties (suppliers and sub-contractors) mainly because there is insufficient information sharing among the parties. Event notification is usually human based, via weekly meetings or even worse, by informal conversations on-site. These methods are very prone to errors and they do not take into account the product supplier companies, which are not involved in the work onsite.

Hence, many times the affected parties receive the incident notification too late to react accordingly and report the incident to their suppliers. This situation is even more problematic in the case of an SME because they lack the flexibility and recovery capability of big companies.

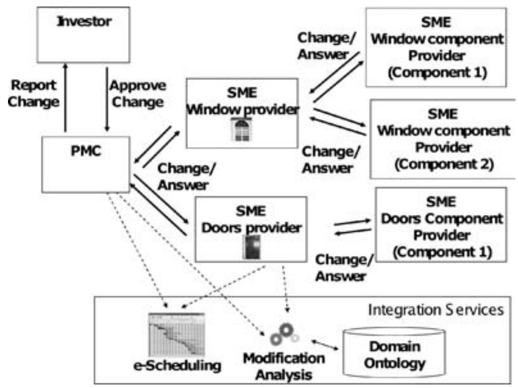

Figure 6. e-Site scenario: Task change event.

The future coordination onsite (e-Site) scenario's main objective is to coordinate operations on the site in real time taking into account the unexpected events that occur at the building site: breakdown of machinery, unacceptable weather conditions, absence of manpower, change in the documentation, etc.

The main functionalities of this scenario are:

- Provide event logging management facilities.
- Update schedules and site documentation according to the incidents and their consequences (the so-called reactive scheduling in).
- Communicate events to the interested parties automatically by electronic means.
- Gather the response proposal to these incidents by the affected partners.

Figure 6 shows a simplified example of the e-Site scenario.

5.3.2 *Construction site Domain concepts*

Based on collaborative modeling research works in the domain of architectural processes, the knowledge needed to deal with collaboration issues on-site can be classified under the following concepts: Event, Task, Actor, Resource (material and device) and Document.

Construction Site Domain provides a common category for concepts related to the e-Site scenario not included in the generic e-Business concepts. It includes among others:

- event related classes. The Event concept describes any problem or event happening on a construction site during construction work stage. It can be of 4 kinds: actor event, resource event, task event or a document event. Each event has a time stamp that describes the date and time when the event occurred and it is related with a target which originated the event. At the same time, the events have a status and a level of importance.

– action (“activity” to be performed by specific actors to solve the problem with its description, identifier, status, date, deadline, companies to notify, etc.)
– environment or the context of the site
– production activity task represents each of the tasks to be performed in the site. They are defined in the master schedule.
– master schedule: the concept that groups the set of tasks to be performed in the site.

5.4 *Quality Domain*

5.4.1 *e-Quality scenario description*

The quality system (control and assurance) is a complex issue that is present in all the steps of the construction work, including the tendering, procurement and the site management processes. The aim of the quality system is to assure the work completion and the quality of the final product.

Although there are quality actions to be applied to all the scenarios, in fact, each scenario has its own quality system. The e-Quality system is centred in two main issues: the documents and their management, and organising all the information and data to perform the tasks according to the work specification and in compliance with the standards.

5.4.2 *Quality Domain concepts*

Quality Domain provides a common category for concepts related to quality aspects. The two main classes are certificates and quality inspections.

A certificate certifies the quality of a product, a material, an organism or a person. The certificate concept includes information about the type of certificate (CE mark, ISO, etc), its name and identifier, the organization that issued the certificate, the date when it was issued, the date when it expires, etc.

Quality inspections represent the inspections that have to be carried out in certain phases of the construction for the purpose of determining if a work or product is complying with regulations and with the client requirements. This class includes information about the characteristic to control, the frequency and equipment needed to perform the inspection control, the person or company responsible, identifier, date, result of the inspection, etc.

6 CONCLUSIONS

It is a fact that the future business scenario will be global, dynamic, open and collaborative. That is why there is the need for exchanging information in a common vocabulary and with the intended precise meaning. Although ontologies have this main motivation, we have come to the conclusion that in order to define a useful ontology, it should be defined specifically for a certain domain and considering its future use.

Up to now, there was no single construction ontology that gathered all the concepts needed to implement e-Business scenarios in the construction sector. For this reason, the e-Business ontology described in this paper fills this gap and provides construction companies with the necessary vocabulary for making business to business transactions and for exchanging information in their internal daily processes. The ontology covers the concepts and relations needed to implement four core e-Business scenarios for the construction sector, i.e. e-Tendering, e-Procurement, e-Site and e-Quality, but it can be easily extended as new e-Business scenarios are considered. Besides, it re-uses where possible existing classification systems in order to develop a compatible model that may contribute to standards.

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General approach to e-NVISION scenarios

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ABSTRACT: The main objective of e-NVISION consortium is the development and validation of an innovative e-Business platform enabling Construction SMEs to model and adapt particular business scenarios; to integrate all their enterprise applications and to incorporate legal, economical, social and cultural services, with the final goal of facilitating their participation in the Future European e-Business Scenario.

The e-NVISION consortium has decided for a bottom-up approach from the construction SMEs standpoint of view. Therefore the definition of future scenarios has been based on the know-how (knowledge and experience) of the SMEs involved in the project and how they would like to work in the future.

On the other hand the "State of the Art" research has been done to guarantee that the work developed is in the line proposed by other experts. e-NVISION has looked into the following sources:

- the European Construction Technology Platform (ECTP) 2030 vision,
- the e-Business w@tch reports in the construction sector,
- the current state in e-Procurement and e-Quality regarding standardization and policies,
- other European projects (mainly from Digital Ecosystem (DE) cluster).

e-NVISION Partners have selected four scenarios, where e stands both for envisioning and electronic:

1. e-Tendering scenario focused on two of the main concerns of the government bodies which are to encourage more SMEs to respond to tender notices as well as to ensure transparency in public processes.
2. e-Site scenario dealing with delays in the construction works and aimed to solve this problem by improving the companies' coordination in the construction time.
3. e-Procurement scenario providing an effective and rational supplier selection model to discover, evaluate and select potential vendors.
4. e-Quality scenario aimed to provide an e-Quality model based on three other scenarios. Resulting from those scenarios Quality Assurance Program will describe quality requirements and how to fulfill them.

The selection has been made basing on twelve project management construction processes and has taken into account both the Strategic Research Agenda (SRA) proposed by the ECTP and recommendations from e-Business W@tch. The four selected scenarios aim to provide envisioning business services enhancing and stimulating SME involvement in construction projects. These scenarios for the future include not only the supply-chain actors, but also other external actors, as regulation providers, quality certification bodies, and so on ("external services"). Also the integration with the internal applications is considered in order to have a holistic view of the business processes. e-NVISION scenarios path the way to envision the capability of business development in the construction relying on the use or the integration of ICTs. Finally, the e-NVISION technical approach for the development of the scenarios defined can be summarized as follows:

- B2B approach can help SMEs to solve their daily problems instead of a centralized approach. Our aim is to isolate SMEs (suppliers and subcontractors) from the complexity of the centralized systems available, which are focused mainly on the necessities of big companies.
- Ontology is the keystone of the dependence between documents and their collection and structuring (collected by the system and based on a model), actions (followed-up by the schedule), and company profile (defining business capabilities of the company and requirements or target for future market or project).
- The future business platform should describe the services using a semantic Web approach, taking into consideration the technical and business view points. This will allow in the future to discover the services needed in real time, making the business platform adaptable and completely independent of the technical details of the service providers.

1 INTRODUCTION

According to the e-NVISION project proposal *"(...) Future business in Europe will be conducted through flexible networks of interdependent organizations. It will be global, open and collaborative, dynamic and adoptive, frictionless and consistent. And it will be electronically supported (...)"*.

According to the European Construction Technology Platform (ECTP) *"(...) the future Construction sector will involve innovative business concepts and innovative business processes resulting in innovative construction products that will be supported/enabled by seamless semantic (forward and backward) communication (object exchange and sharing) throughout construction product/service life-cycles and their associated supply chains, based on generic, open and web-based standards (...)"*.

During the past years there have been different industry efforts for representing the behavior of business processes as well as for defining business process integration, orchestration or choreography models. These include WSCI, BPML, XLANG, WSFL, WSCL, BPSS, the Web Services Architecture, and most recently BPEL4WS or BPEL.

In parallel with these industry efforts, the Semantic Web community has been developing languages and computing machinery for making Web content unambiguously interpretable by computer programs, with a view to automation of a diversity of Web tasks. Efforts include the development of expressive languages including RDF, RDF(S), DAML+OIL and OWL. In the area of Web Services, the Semantic Web community has argued that true interoperation requires description of Web Services in an expressive language with a well-defined semantics. To this end, there are different initiatives among which we can mention OWL-S (an OWL ontology for Web services), WSMO (Web Service Modeling Ontology) or SAWSDL (Semantic Annotations for WSDL).

In addition, researchers have developed automated reasoning machinery to address some of the more difficult tasks necessary for seamless interoperation including a richer form of automated Web service discovery, semantic translation, and automated Web Service composition.

However, still this complex but advanced knowledge has not reached in a practical way the SME real world, because today's approaches, methods, techniques, and standards still require developers to work at very low and detailed implementation levels far removed from real business needs, practices, and contexts.

For this reason, SMEs are playing the leading role in this business analysis but always in short collaboration with ICTs and RTDs in order to provide to this business analysis an also important technical view. This technical approach will offer the basis for the implementation of today's Web Service (WS), Semantic Web Service (SWS) approaches, methods, techniques, standards and so on that are too complex to be understood by SMEs themselves.

The most suitable e-Business scenarios have been defined not only considering the current SMEs, but also considering other potential actors. At this stage some of them could seem fictitious or unrealistic but we should not discard them.

All the above has motivated the e-NVISION consortium to do a bottom-up approach from the construction SMEs standpoint (that is, taking into account current construction trading lifecycle scenarios and processes) to a complete infrastructure definition of a collaborative and SME oriented (e-NVISION) trading lifecycle scenario.

This bottom-up approach consists of four phases:

1. Definition of the current construction processes by business experts, that is, construction SMEs involved in the project.
2. Selection of the most appropriate construction business processes to be envisioned in order to focus on the most relevant ones from the point of view of the project.
3. Gathering of envisioning ideas by business experts (through brainstorming sessions)
4. Informal Definition of the e-NVISION scenarios via story telling taking into account all the above and incorporating "higher" level goals to their process definition, such as customer perceived value, whole life performance, legal, social, economic, trust and if possible, sustainability aspects.

2 CONTRIBUTION OF E-NVISION TO THE STATE OF THE ART

e-NVISION understands that its main contribution to the Construction Community is not the development of another powerful platform, but the definition and conceptualization of new e-Business scenarios and the development of specific data models, external and integration services. These data models will provide the basis for the standardization of the concepts managed in construction processes. In addition the external and integration services will facilitate the up to now hazardous task of adopting and entering into the e-Business world especially for SMEs. The contributions of the e-NVISION project can be summarized as follows:

– Definition of an e-Business model defined and developed by the Construction SMEs, this is why we have chosen a bottom-up approach. We have studied some recent developments in the

ontological representation of the IFC model, like for example e-Cognos. However, we have decided to develop our own models since e-Cognos has been developed to deal with knowledge management issues and not specifically having e-Business in mind.
- Definition and Development of external services that help SMEs to participate in e-Business transactions. These services will include among others, legal, economic and trust aspects.
- Definition and Development of integration services with the SMES' backend enterprise applications.

3 CURRENT CONSTRUCTION PROCESSES

In order to define the future scenarios a preliminary analysis of the current processes that takes part in the Construction Process was done. The processes analyzed were the following:

- PM-01: Tender and agreement with the General Contractor.
  General description: Cooperation with the Investor in choosing the General Contractor (GC) of works and conclusion of the agreement with the Contractor.
  Ensuring supplementation of agreements, arrangements made in the form of annexes, approvals in the case of occurring or introducing changes during the completion of technical and structural designs, detection of faults in reference to the applied construction materials, structures or furnishing.
- PM-02: Control of design documentation
  General description: Verification of the formal contents and completeness of design documentation, organization of the Investor's opinion-giving process (approval and opinion-giving) in reference to detailed designs.
- PM-03: Planning and scheduling
  General description: Development of the particular realization timetables (operating plans, schedules), with the use of PRIMAVERA or MS-PROJECT specialized software.
- PM-04: Construction coordination
  General description: Coordination of the activities of the General Designer (GD), General Contractor (GC), Investor and its own (PMC – Project Management Company) as refers to construction and assembly works, services or deliveries of equipment and materials, in order to keep to the deadlines determined in the Master Schedule.
- PM-05: Investor's supervision
  General description: Investor's supervision in all present disciplines.
- PM-06: Marshalling of machines and equipment deliveries
  General description: Cooperation with the Investor in marshalling machines and equipment deliveries, including: preliminary qualification of producers, preparation of quotation inquiries, qualification of the received quotations, negotiating agreements and purchases, quality control, organization of transport, warehousing and distribution on site.
- PM-07: Organization of process start-up
  General description: Organization of an interdisciplinary team, consisting of the representatives of the parties, for the purposes of process start-up.
- PM-08: Preparing reports
  General description: Organization and keeping of current reporting, notifying the Investor on the current progress of works, as well as the use of funds and the present departures from the plan.
- PM-09: Control of costs and financial settlements
  General description: Registration and control of Project expenditures and costs, financial reporting and the principles of the Project settlement.
- PM-10: Final acceptance and report
  General description: Final acceptance and settlement (report) of the Project completion.
- PM-11: Development and implementation of Quality Assurance Program
  General description: Development and implementation of Quality Assurance Program for the Project, in cooperation with the General Contractor, including any procedures and specimen documents.
- PM-12: Supervision of safety and health at work matters
  General description: Coordination of the activities of all the parties participating in the completion of investments referring to safety and health at work.

4 FUTURE E-BUSINESS SCENARIOS

4.1 *Process selection*

The criteria used for selecting and defining the business processes have been:

- Scenarios that can be applied in the Construction Sector, providing new interactions between the actors (PMC, Suppliers . . .).
- Scenarios that allow SMEs to participate with other roles, that up to now were almost impossible.
- Scenarios focused on B2B interactions.
- Scenarios that make it possible to create new services and actors like ICT Suppliers, Financial, Regulation Agents
- Scenarios that include Legal / Cultural / Socioeconomic / Quality aspects

During the 1st Technical Meeting of the e-NVISION project held in Nice (France) in March 2006, four processes were selected from the twelve already identified by the SMEs involved in the project.

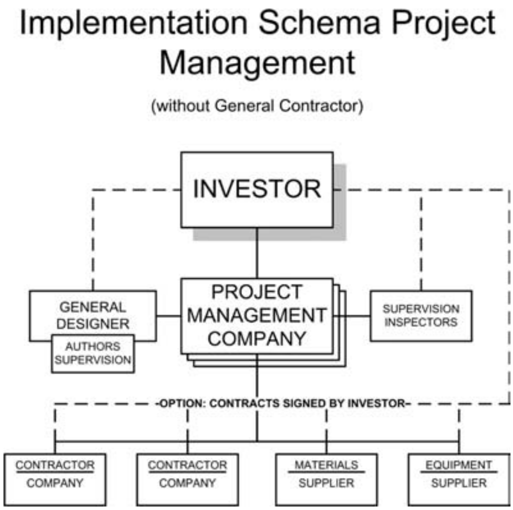

Figure 1. Implementation schema Project Management.

These four have been selected to be envisioned because they best fulfill the above criteria:

– PM-01 Tender and agreement with the General Contractor.
– PM-04 Construction coordination.
– PM-06 Marshalling of machines and equipment deliveries.
– PM-11 Development and implementation of Quality Assurance Program.

In order to adapt the selected scenarios more to participation of SMEs it has been decided during the 1st Technical Meeting that PM-01 will concentrate on Tenders and agreements with participation of several Contractors from various disciplines without call for tender for one General Contractor (GC).

Because there will be no GC chosen his role in PM-04 will be taken over by Project Management Company (PMC) e.g. consortium of SMEs or Virtual Enterprise (VE) or one SME (e.g. medium size enterprise). Furthermore a group of several Contractors instead of one GC will allow SMEs to participate in tenders for construction-assembly works individually or as consortia of them. Please refer to enclosed below Project Management implementation diagram

For the same reason it has been also decided that PM-06 will be regarded in more general way i.e. as Procurement (not Marshalling) organized by PMC and will allow participation of SMEs as suppliers.

5 ENVISIONING SCENARIOS

The four construction processes were envisioned. To distinguish between the current processes and the envisioned processes we will refer to the future scenarios as:

– PM-01 e-Tendering
– PM-04 e-Site
– PM-06 e-Procurement
– PM-11 e-Quality,

where e stands for envisioning and electronic.

The e-Tendering scenario will focus on two of the main concerns of the government bodies and institutions which are to encourage more SMEs to respond to tender notices as well as to ensure transparency in the public processes. A way to enhance and boost the rate of supplier participation, especially among small and medium-sized enterprises (SMEs) is to:

– make markets more transparent through better information;
– boost the reliability of contract award procedures through training focused on professionalism and best practice;
– take action to make public tenders more accessible to SMEs;
– provide for mutual recognition of national supplier qualification systems, so that a supplier who has obtained qualification in one Member State can use that qualification in other Member States without having to demonstrate his suitability over again.

The e-Site scenario will deal with changes in the construction works. Nowadays, when there is a change in the construction works, the affected participants (subcontractors, suppliers) sometimes are not aware of the change till it is too late to react. The e-NVISION project will try to solve this problem by improving the companies' communication at the construction site. Any change at the construction site will be automatically reported to the interested partners so that they can react as soon as possible.

The e-Procurement scenario will provide an effective and rational supplier selection model. Nowadays, it is difficult for new supplier-SMEs to start working with an investor if no previous contacts have taken place between them. With increasingly global world markets, companies are under pressure to find ways to cut production and material costs to survive and sustain their competitive position in their markets. The e-NVISION project will provide an effective and rational, world-wide supplier selection model to discover, evaluate and select potential providers.

The aim of the e-Quality scenario is to provide an e-Quality model compliant with the country where regulation is applied. To do so, the e-NVISION project will define an e-Quality model based on three other scenarios i.e. e-Site, e-Tendering and e-Procurement. Resulting from three scenarios Quality Assurance Program will describe quality requirements and how to fulfill them. The solution will provide a sort of

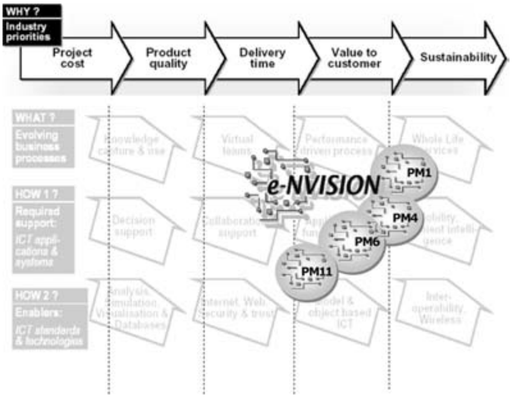

Figure 2. Envisioning scenarios.

interactive system to remind SMEs, suppliers and other actors of the construction works to deliver the last version of their documentation each time the system detects an event (new stage, new official document delivered, new site work modification).

Figure 2 shows in a graphical way where these envisioning scenarios will be located inside the representation of the ECTP Vision.

e-NVISION will try to make use of the current matured ICTs to enable these envisioning scenarios to become a reality. Some of the foreseen technologies can be grouped by:

– Security/Trust/Social Services
– Models, Ontologies
– Semantic Technologies
– Digital Business Ecosystem, Interoperability

6 E-TENDERING SCENARIO

6.1 *Current storytelling*

Due to the low results obtained in the previous Olympic Games, the local government decides to invest money in the construction of a sports centre with a high performance centre.

On the customer side:

Roger the person in charge of the new investment project for local government of MyTown sends the call for tender advice and summary to the MONITOR: a professional construction periodical and the call for tender is published three weeks after the send.

Roger's secretary has received many phone calls and sent more than forty application forms to applicants while Roger took time to give additional information to applicants.

The call for tender is closed now, and Roger has received around sixty paper propositions. Most of these paper propositions, around 55, are from big companies and all of them are from companies of the same region or geographical area of activity.

Even if some of them do not respect the formal standard initially proposed, Roger will have to read, analyze and understand all the different proposals before making a first selection. It will take to Roger more than one month before he is able to start the negotiation with the contractors.

On the SMEs side, case 1:

Jim the person in charge of BUILD Ltd, finds out this call for tenders while reading the MONITOR and informs his boss (Jack) of the great opportunity this tender could be for their company. Jim and Jack know how to construct buildings so they get in contact with their preferred suppliers. However, they have never built a sports centre before and do not know of any company that can build the specific grass field demanded in the tender for the hockey field. On the other hand, they would need to apply for the tender with a company that builds the stands for the athletics track and a company that builds swimming pools. Jim and Jack only have one month to prepare all the documentation and start the negotiation process. Jim starts looking for regional companies that build the specific grass field, stands and swimming pools. It takes Jim one week to find SWIM Ltd and STAND Ltd, two companies in his region. However he is not able to find any company that can build the specific grass field in his area of activity. Three weeks later Jim informs his boss that there are companies in Germany that make this kind of grass fields but they do not have any reference or time enough to get in contact with them. Unfortunately BUILD Ltd has run out of time and cannot participate in the tender.

On the SMEs side, case 2:

Jim the person in charge of BUILD Ltd, finds out this call for tenders while reading the MONITOR and informs his boss (Jack) of the great opportunity this tender could be for their company. Jim and Jack know how to construct buildings. However, they have never built a sports centre before and do not know of any company that can build the specific grass field demanded in the tender for the hockey field. On the other hand, they would need to apply for the tender with a company that builds the stands for the athletics track and a company that builds swimming pools.

Jim and Jack consider there is not enough time to look for the companies or negotiate the conditions so they decide not to make the effort or waste resources and they do not even try to participate in the tender.

6.2 *Envisioning Storytelling*

Due to the low results obtained in the previous Olympic Games, the local government decides to invest money in the construction of a sports centre with a high performance centre. Therefore it publishes a call for tenders in the CFTP (Call For Tender and Procurement).

On the customer side:

Through the URL, Roger the person in charge of the new investment project for local government of MyTown connects to CFTP site.

He is guided and helped to structure, and upload files to complete the project call for tender on-line site and repository.

Having checked and tested the new generated call for tender site, Roger decides to officially invite participants to the tender. The call for tender is sent to all the SMEs that are subscribed independently from their area of activity, region, or country. The time consumed before all the SMEs receive the documentation is 1–2 hours.

CFTP is an innovative multi-lingual cross-border information service to facilitate both electronic e-Tendering preparation for private/public companies and public/private procurement throughout Europe. Such a service facilitates finding public and private procurement information via a single point of access, and makes it easier and cheaper to obtain and re-use the information when achieving tenders. In conclusion this service is far less time-consuming and costly process, and at the same time allows an open and transparent European-wide electronic market for procurement.

The call for tender is closed now, and Roger has received around 150 propositions. Some of these propositions are from big companies, around 110 but there are also about 40 propositions from virtual enterprises of SMEs. Most of the participants are companies from the same region as MyTown but there are also about a 30% of companies from other regions and countries.

The CFTP allows making automatically a first selection of propositions by discarding those that do not respect the formal standard initially proposed or that do not meet certain criteria.

On the SMEs side:

BUILD Ltd is an SME construction company.

Jim, a project manager from BUILD Ltd, is a recognized member of the CFTP site. This means that he has previously registered information related to BUILD Ltd company as for example details of its profile, skills and experiences, preferred collaboration forms and contractual templates, as well as its offer (and even demand) of products and services. To this purpose the CFTP site is supported by the local ontology providing lexicon and concepts to associate the right metadata to the stored data. The work is done in the home language of the company.

As soon as MyTown has submitted its call for tenders, and as a result of the correlation between MyTown project requirements and BUILD Ltd skills and know-how, Jim automatically receives the bid request for quotation of the project by email.

Jim informs his boss (Jack) of the great opportunity this tender could be for their company. Jim and Jack know how to construct buildings so they get in contact with their preferred suppliers. However, they have never built a sports centre before and do not know of any company that can build the specific grass field demanded in the tender for the hockey field. On the other hand, they would need to apply for the tender with a company that builds the stands for the athletics track and a company that builds swimming pools.

This is not a problem because the tender service has detected that BUILD Ltd's skills do not cover some of the tender's needs and sends a list of companies that build the specific grass field, companies that build stands for the athletics track and companies that build swimming pools. The list of available companies (some from his area of activity, some others from different regions and some from other countries) is ordered by a certain criteria and with the guarantees and references offered by Trust Bros Company as well as the quality control and certification documents offered by Legal Association.

Although Jim and Jack only have one month to prepare all the documentation and start the negotiation process, this is time enough. They choose from this list 2 German companies, 3 companies from their area of activity and 2 companies from a near region. After two weeks of negotiation, BUILD Ltd reaches an agreement with 3 of these SMEs (GRASS Ltd that is a German SME, SWIM Ltd and STAND Ltd) and they all together participate in the tender as a virtual enterprise. Finally, the CFTP site guides and helps to structure, and upload files to complete the sports centre project call for tender and the virtual enterprise's proposal is submitted on time.

6.3 *Why is it envisioning?*

There are several factors that make this e-Tendering scenario approach envisioning.

Firstly, the Electronic SME network management. Nowadays most common scenario is that a big company participates on its own in call for tenders and subcontracts to SMEs some parts of the tender works.

Small companies do not have the possibility or the means to associate among themselves in order to participate in a tender call. The envision SME configurator will solve this issue.

Secondly, the Electronic tender decomposition and Profile-works mapper. These internal services allow automatically looking for and finding a set of SMEs that can perform certain tender works.

Finally, the Electronic trust management. Currently the figure of an external agent such as a quality control and certification entity does not exist. This agent would offer a service that provides certain trust parameters such as: litigation or claim proceedings per year, debts and overdues, accusations, accidents, financial and fiscal aspects, etc.

7 E-SITE (CONSTRUCTION COORDINATION) SCENARIO

7.1 *Current storytelling*

When the crane of the construction site of the new Hospital of MYTOWN suddenly goes out of order, the Site Manager informs the Project Manager of the situation. They need to evaluate the impact on the current ongoing process activities and to identify how to reorganize the work. They phone the affected partners to inform them about the incident. However, they cannot get in touch with BARBENER because at that moment the manager's mobile phone is out of coverage. As they are so busy with the crane incident they forgot to phone again.

Two days after the crane failed out, BARBENDER company delivers the reinforcements. When the delivery truck arrives on the site, the construction site manager has to find a rapid solution both to unload the truck and to find a free storage area. At present time, it is difficult to assess precisely the storage area content, partially because the stock inventory has not been done and due to the fact that many materials have been delivered and momentarily stored while expecting the crane reparation. Meanwhile, the driver is not able to park the truck in the construction site, causing some traffic problems. Finally, the site manager is not able to find enough place to store the reinforcements and the truck must go back to BARBENER. BARBENER decides to provide part of the reinforcements to another customer and reorganize its production processes. After a couple of days BARBENER receives a phone call from the site manager of the new Hospital asking for the reinforcements since it has been possible to arrange some storage place for them. However, BARBENER is not able to provide the reinforcements until the production line is set up for the new order. The new Hospital of MYTOWN construction process suffers another annoying delay.

Due to the lack of anticipation, the coordination of the project must be based on a large experience of previous problems and unexpected event management from day to day.

7.2 *Envisioning Storytelling*

The construction site of the new Hospital of MYTOWN has started 5 months ago. It should finish in one year.

After earthwork and foundation phases, the first floor of the main building is above ground and the floor slab of the second floor is now under construction.

BARBENDER company was informed (a week ago) by email/SMS that its "window" of reinforcements delivery was to take place at 2PM tomorrow.

Suddenly, the crane of the construction site of the new Hospital of MYTOWN goes out of order. The construction Site Manager informs the Project Manager of the situation. They need to evaluate the impact on the current ongoing process activities and to identify how to reorganize the work. The time needed to put in order the crane is introduced as a delay in the electronic scheduler via a PDA and the electronic scheduler automatically find what suppliers and subcontractors are affected by the change. The Project Manager checks the list of affected partners and allows the scheduling system to send and electronic message to all of them. The system keeps waiting for an acknowledge message from every partner, so that the Project Manager is sure that the message had been received.

Two days before the delivery, the BARBENDER delivery manager receives a message indicating to him to postpone (defer) its delivery to the following day under the reason that the crane requires an intervention of maintenance following a breakdown. This way, BARBENDER checks that there is not problem since it has enough time to reorganize its production line and logistics, so it sends an electronic ACK to the constructor.

7.3 *Why is it envisioning?*

This scenario is envisioning from several points of view. It implements a Business Process within a SME. Nowadays, most companies are organized around departments and departmental applications (HHRR, CRM, Financial, ERP, etc.). The e-Site scenario requires a new application (B2B platform) to implement the whole process using the rest of the applications as services.

From the point of view of internal applications we have defined two completely new services, and this new services need to use semantic information and reasoning in order to be automatic.

Finally, the creation of the systems explained above implies a cultural change in many companies, especially in the micro SMEs (ten workers or less). An ASP (Application Service Provider) model could be a good approach in order to avoid infrastructure investments.

8 E-PROCUREMENT SCENARIO

8.1 *Current storytelling*

BUILDALL Company succeeds in the call for tender. George as the project manager prepares the kick-off of the construction stage.

George is looking for suppliers of machinery and equipment for the construction such as lifts, HVAC (Heating, Ventilation, Air Conditioning) units, pumps, substations, etc.

George consults the business directory where he can find machinery and equipments providers. He selects the required products and identifies potential providers. He usually chooses the same suppliers as last time.

He asks his secretary to send a fax to the list of potential providers calling them to show their interest in deliveries for the project.

Gloria, his secretary, reads the list of suppliers given by George and notices that one of the suppliers selected by his boss is the one last year they had a serious product (poor quality) problem with. Then, she reminds George about it and George asks his secretary to look for any similar supplier in a hurry.

Gloria connects to Google and look for other suppliers, she finds several of them but no one provides information about their quality, only price is advertised, so, she decides to choose one at random.

There are probably much more other suppliers but as they are not properly advertised it is difficult to find them.

Three days after, John has received only one proposition but various information are missing and he needs to call back the supplier.

8.2 *Envisioning Storytelling*

BUILDALL Company has succeeded in the call for tender. George as the project manager prepares the kick-off of the construction stage.

HVAC+ and HVACRETIZE are SMEs registered in a public advertising directory (along with many other SMEs like themselves).

Thanks to e-Procurement, George can create a request to find providers for the supply of machinery and equipments for the construction such as lifts, HVAC (Heating, Ventilation, Air Conditioning) units, pumps, substations, etc.

George fulfils a standard form with predefined category of machinery and equipments. He selects the required product with its specification. Additional criteria such as the opportunity or the need to find a local provider can also be captured.

George plans the required activities, indicates as additional resources its usual partners and fixes scheduling conditions and constraints. On the basis of the scheduler outcome, George uses the system to automatically send the relative requests for quotation to the scheduled partners.

e-Procurement service proposes then a list of European wide potential provider. As soon as George validates the request he gets a list of potential provider. He has the possibility to make a pre-selection before the bid is send for the quotation.

The request is broadcasted to the "SME" companies of interest.

Within the fixed deadline George receives indications (in particular regarding the HVAC procurement) for five candidates that have searched and selected by the e-NVISION system. One of them, HVAC+, is particularly interesting and George starts negotiating with it until a quotation has been obtained.

George takes its time to compare with an additional quotation coming from HVACRETIZE. The day after, George makes his choice and send the electronic contract to the selected company: HVAC+ (while the system automatically closes the negotiation with the other).

Information such as packaging, payment modalities, contract conditions are detailed in the document. In addition requirements on the choice of appropriate delivery route and time are mentioned in the document.

In case of unexpected problem on the site delaying as an example the delivery, HVAC+ will be taken informed by the system.

8.3 *Why is envisioning?*

As explained before, this new scenario allows the participation of the biggest number of SMEs (suppliers) and more complicated ways of collaboration among them.

Therefore this envisioning scenario will match in an appropriate an optimal way the demand (Investor needs) and the offer (supplier services) deploying the requested e-marketplace in the envisioning ideas.

In this e-marketplace the products and services will be published allowing different ways of interdependences between them to provide the best matching mechanism for a specific market need.

9 E-QUALITY SCENARIO

9.1 *Current storytelling*

CONSTRUTEC a construction company has succeeded to a local tender, and is in charge of the construction works. CONSTRUCTEC, which is a SME has to begin the work. To prepare the work, it has to collect information about current regulation and standards in order to comply with them. Moreover, it has to get all licenses and authorizations in order to start the work. Therefore, CONSTRUTEC has to identify the providers to obtain all this information.

Once known the applicable standards, CONSTRUTEC has to define a complete schedule of the work, with products, materials, timing, companies involved and the quality documents which specify all of them.

However, Bill, who is project manager of CONSTRUTEC, is aware that during the site construction works, some modifications happened on the openings mainly because the provider changed its range of products. He is not absolutely sure that he gets the latest version of the documentation/specification for the windows of the first floor.

As a result, Bill has to call the windows provider in order to check what type of windows have been finally delivered and installed. Even if Bill updates all documentation to gather these changes, there is a high probability not to have an up-to-date version of the documentation coming with the construction for the delivery.

9.2 *Envisioning storytelling*

A Spanish developer GREENHOME has bought a land in Warsaw for the big project of 1000 of apartments temporarily called SMALLBILBAO.

A Spanish windows producer SPAINWIND knowing about the GREENHOME project is interested to supply windows for SMALLBILBAO. SPAINWIND has already cooperated with Polish civil structure contractor POLBUD. POLBUD as a subcontractor for another project in Warsaw has installed SPAINWIND windows. Both companies have decided to organize Virtual Enterprise (VE) called SPOL for the SMALLBILBAO project. POLBUD because of the very good knowledge of Polish construction regulations became the leader of SPOL VE. Thanks to e-NVISION POLBUD and SPAINWIND have gathered POLISH civil structure SME contractors, Spanish SME windows producers, Slovenian SME roads contractors and Lithuanian SME finishing works contractors together with French SME innovative ecological finishing materials producers organized as SPOL VE. GREENHOME had a lot of doubts concerning SPOL SME companies offer, but finally was convinced by SPOL e-Quality Model.

As the Polish construction regulation requires "Occupation Permit" also called "Permit for usage" this document has to be obtained by GREENHOME PM to complete the project. In order to obtain it a lot of documents has to be gather both technical information (as-build documentation, site log book) and administrative settlements (fire protection, sanitary, utilities supplies).

e-Nvision e-Quality Model offers a structured/controlled system to collect and check the quality through the different steps of the project using the "Final Documentation" structuring. e-Nvision collaborative server can collect documents using workflow mechanisms. The collecting is done all along the project progress since there is a strong relation between the different stage of the project and the documentation available or required for each stage. There is also a strong correlation between site works "modifications" and design documentation.

The solution provides an interactive system to remind SMEs, providers and other actors of the project to deliver the last version of their documentation each time the system detects an event (new stage, new official document delivered, new site work modification). The workflow defines steps of the validation process for the document. This follow-up guaranties that 100% of documents are collected, have been validated and are up-to-date.

In fact it was the e-Quality Model being part of e-NVISION that has allowed SPOL VE to win the tender for SMALLBILBAO project.

9.3 *Why is it envisioning?*

The quality of the construction is becoming a key aspect in all kind of constructions due to the legal responsibilities.

All the aspects related, not only with the quality of the equipments and installation, but also with the safety and health at work, fire safety and environmental protection will have to be registered, traced and controlled during the whole life of the building (the construction will be only one of the phases of the project). Quality certifications will be demanded even before starting the construction process itself.

The quality of a product (like a car, an electronic device, even a software) can be seen very often through the documentation coming with e.g. user manual or exploitation manual.

e-Quality Model provided by e-NVISON is a generic and scalable one. In order to focus on a tangible and visible aspect of the quality, e-Quality model will implement the final documentation model that should be required for the delivery of the construction whatsoever its occupancy or use.

This ICT based solution will give the opportunity for the Investor and the PMC to provide an useable documentation to their customer i.e. e-NVISION e-Quality Model provides a methodology to collect the documentation and by searching side effect that may cause a decision due to an unexpected change on the site as an example.

The methodology of collect will be empowered by added-value functionalities such as:

- Automatic requesting of SMEs documentation.
- Automatic generation of non-compliances, defining responsibilities, and the preventing and corrective actions.

– Automatic requesting of pending certifications.

e-NVISION can later implement specific functionalities providing additional interesting services such as:

– Automatic definition of the demanded quality certifications.
– Automatic registration of tests and inspections.
– Electronic signing of certifications, tests, and inspections reports.

The "Final Documentation" is an example of an operational quality model and can be derived to comply with each European Country need.

10 CONCLUSION

The definition of four future scenarios has been based on the know-how (knowledge and experience) of the SMEs involved in the project and how they would like to work in the future.

In addition, research has been done to guarantee that the work developed was in the line proposed by other experts. e-NVISION has looked into the following sources:

– the European Construction Technology Platform (ECTP) 2030 vision,
– the e-Business w@tch reports in the construction sector,
– the current state in e-Procurement and e-Quality regarding standardization and policies
– other European projects (mainly from Digital Ecosystem (DE) cluster).

The selection has been made basing on twelve project management construction processes and has taken into account both the Strategic Research Agenda (SRA) proposed by the ECTP and recommendations from e-Business W@tch.

1. e-Tendering scenario focused on two of the main concerns of the government bodies which are to encourage more SMEs to respond to tender notices as well as to ensure transparency in public processes.
2. e-Site scenario dealing with delays in the construction works and aimed to solve this problem by improving the companies' coordination in the construction time.
3. e-Procurement scenario providing an effective and rational supplier selection model to discover, evaluate and select potential vendors.
4. e-Quality scenario aimed to provide an e-Quality model based on three other scenarios. Resulting from those scenarios Quality Assurance Program will describe quality requirements and how to fulfill them.

The four selected scenarios aim to provide envisioning business services enhancing and stimulating SME involvement in construction projects. These scenarios for the future include not only the supply-chain actors, but also other external actors, as regulation providers, quality certification bodies, and so on ("external services"). Also the integration with the internal applications is considered in order to have a holistic view of the business processes.

e-NVISION scenarios path the way to envision the capability of business development in the construction relying on the use or the integration of ICTs.

10.1 *e-NVISION scenarios vs External Sources vision*

In coherence with ECTP and in particular with the focus area "Processes and ICT", e-NVISION scenarios will contribute to medium-term research topics in the domain of:

– Methods for verification and documentation of functionality, comfort and other quality requirements from customers.
– Models for handling management program requirements, including documentation demands related to operation and maintenance.
– Development of industry standards and effective de-facto standards for data exchange, object definitions and integrated model servers.

10.2 *Main findings and e-NVISION approach*

The main findings can be summarized as follows.

– The construction sector lags behind other sectors regarding ICT uptake and e-Business adoption. In fact, some of the scenarios suggested by the RTDs were at first rejected by the SMEs, because they were considered too advanced and not realistic.
– The SMEs' vision is not very far from the future trends taken from the sources consulted.
– The needs of the PMC are not the same as those of suppliers (SME or not) or subcontractors. That is why the storytelling have two points of view: the PMC's and the view of the other actors.
– Although quality has been identified as being a very important issue, it has not been possible to define a quality process itself. Quality related activities are embedded in the other processes (e-Site, e-Procurement and e-Tendering).

Finally, the e-NVISION technical approach for the development of the scenarios defined can be summarized as follows:

– B2B approach can help SMEs to solve their daily problems instead of a centralized approach. Our aim is to isolate SMEs (suppliers and subcontractors) from the complexity of the centralized systems available, which are focused mainly on the PMC necessities.
– Ontology is the keystone of the dependence between documents and their collection and structuring (collected by the system and based on a model), actions (followed-up by the schedule), and company profile (defining business capabilities of the company and requirements or target for future market or project).
– The future business platform should describe the services using a semantic Web approach, taking into consideration the technical and business view points. This will allow in the future to discover the services needed in real time, making the business platform adaptable and completely independent of the technical details of the service providers.

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e-Tendering – The business scenario for the e-NVISION platform

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ABSTRACT: The Objective of the article is to describe and analyse weakest links in current tendering process, based on already performed questionnaire-based research and to propose implementation of services, demonstrating possibility to strengthen these weakest links in the process for SMEs to enable them through e-tendering to have more involvement and more presence in the industry. Aforementioned issues make very strong impact to SMEs. The e-NVISION platform provides a solution – e-Tendering scenario. The main objective of e-Tendering scenario is to enhance SMEs participation in calls for tenders. The main goals of envisioned tendering scenario are: 1) To increase collaboration level among SMEs and improve their chances to compete on equal footing compared to bigger tenderers (e.g. as a group of SMEs or as a Virtual Enterprise); 2) To reduce the work needed to analyse hard copy proposals; 3) To be proposed in a way of open and transparent world-wide electronic market; 4) To implement mechanisms to look for partners interregionally and internationally; 5) To support external organizations by providing trust and quality.

1 INTRODUCTION

According to the e-NVISION project technical annex: "< . . . > e-Business is the first and most critical step in which the companies must be established in order to guarantee their survival and stability. < . . . > The current global e-business solutions existing in the market are too general and complicated to be used by a small or medium company. < . . . > The main barriers SMEs to exploit and adapt will be the lack of methodologies to migrate to e-Business practices, a target reference and proven SME-oriented e-Business model and a cost-effective, tailored and ubiquitous technological solutions and toolkit to support (automatically) these processes". The main goal of e-NVISION project was to provide such solution for SMEs in building and construction sector.

This article provides one of identified e-business scenario – e-Tendering. Taking in account the results of performed survey it was stated that: "< . . . > The construction business starts with the tendering procedure, being a tender for design, tender for works, supply of goods or combination of them. The e-Tendering process should provide a secure means to exchange the tender information and conduct tender events (including the negotiation process) over the Internet."

2 BASIC ASSUMPTIONS

The envisioning scenario will have to take into account that the time for preparing a tender is limited (and very short); that there is a strong interregional and international competition (big contractors are bidding for a tender); that the members of the foreseen virtual enterprise do not know each other before this construction project and the different regions or countries procurement policies, directives, agreements and practices.

The e-Tendering focuses the envisioning efforts mainly on three of these tasks:

– Create new tender. A new data model has been defined that will enable automatic tender processing of the type of tender, the works to be performed, the skills required, the documentation to be provided, etc. This Tender Model will contain a structured representation of, among other.
– Send call tender notification. This service would constantly check different national and European means (portals, papers) where the invitations to tenders are published. It could also offer the possibility to publish (private) tenders directly. In addition, it could send tender notifications to registered SMEs depending on their skills and preferences.

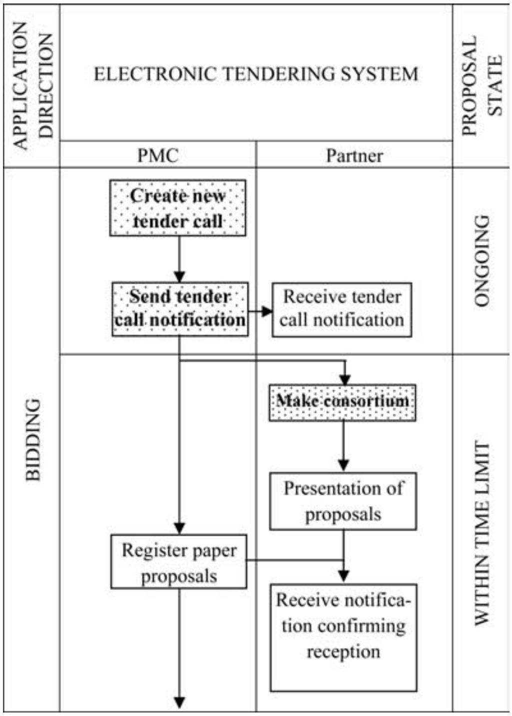

Figure 1. This schema expresses the general flow of e-Tendering. The Project management company (PMC) creates new tender and starts collaboration with possible partners. The dotted boxes represent e-NVISION improved areas in tendering.

– Make consortium. The e-NVISION project boosts the equal footing, providing all companies, especially SMEs, the capability to compete for public (and private) contracts. e-NVISION allows and fosters different SMEs to associate as a group or virtual enterprise, in order to bid for a contract.

The processes involved in the other tasks (further after Bidding phase go Legal documentation classification, Opening of proposals, Reckless drop-off presumption, Award and formalize contract) are being covered by applications that local governments are already developing. This is the reason why the e-NVISION project has decided to stress the work on these three tasks (Fig. 1):

Further these three tasks will be explained with more details by explaining used data models and functionality of web services.

3 CREATE NEW TENDER CALL

3.1 *Start of tender*

The tendering awareness phase starts when the SME (in this case SME is PMC – Project Management Company or GC – General contractor) receives a notification of a new tender call. This notification will be sent by an external agent, for example, the EU Public Tender Service (like CFTP – Call for Tender and Procurement). The company can visit official websites or read official bulletins from time to time to be aware of new tender calls, etc.

Assuming the most possible ways to start e-tendering phase, scenario can be activated in three different ways:

– By a human activation. A user is informed about a tender and the Tender Analysis sub- process starts.
– In the case the company is subscribed to the Tender Awareness service, by receiving a notification from this service by e-mail.
– By receiving an invitation message from another construction company to participate in the tender.

In general case it is assumed that SME gets automatic tender notifications. Next, the SME (responsible manager) will decide whether to participate or not and if so, will ask for the full documentation.

Some more tasks should be accomplished before particular SME will be able to get the notification for tender:

– Some SME (or SMEs) should be subscribed for tender awareness and configuration services to be notified about new possible tender.
– Other SME should be registered for CFTP like services to be able to provide new tender.
– Some new tender should be provided.

Next sub-sections will describe these steps more precisely.

3.2 *Subscription for tender*

By this task SME registers to services and receives invitations[1] to tenders and stores personal information[2] by filling a registration form (Fig. 2 and 3).

The registration process must ensure the confidential transfer and storage of all personal information of users. Furthermore, mechanisms may be put in place for the validation of the information provided by new users of the system. Hence, the registration process may be performed in two phases. One phase can allow new users to apply for registration to the system, and

[1] SME get direct invitation from tender awareness service if its profile fits tender profile. In other case (if such company profile fits for tender only partly) the SME can get message from GC if it goes (by specified criteria) to general list of possible partners or subcontractors.

[2] Users can update their personal information if required also (not discussed in this scenario). This information can be used for automated notifications of tenders that request products or services offered by the user.

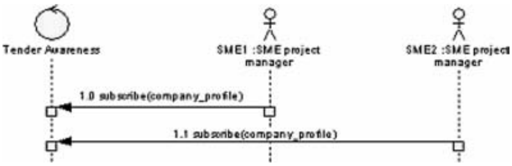

Figure 2. SME subscription for tender awareness service. Each SME interested in bidding for tender (in role of PMC or GC) is subscribing for this service by providing its profile.

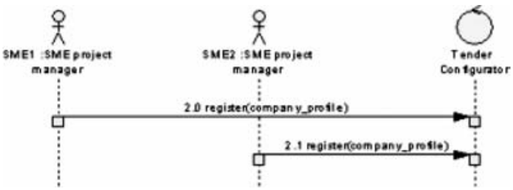

Figure 3. SME subscription for tender configurator service. Each SME interested in participation in call for tender (in role of Partner or sub-contractor) is subscribing for this service by providing its profile.

another phase can allow authorized personnel to validate the submitted information and approve or reject a registration application[3].

Tender awareness allows users to register to e-NVISION services and to receive invitations to tenders and store personal information of its registered users and companies, by filling a registration form.

The Tender Configurator will be in charge of analyzing a tender, identifying the tender matter and according to the tender model decomposing the tender matter in sub-tenders or sub-works that can be carried out by and matched to different profiles of SMEs, i.e. if we consider a tender to build a house we can divide it in a sub-tender for the windows, a sub-tender for the doors and so on. This way, the Tender Configurator will offer several possible Virtual Enterprises or groups of SMEs with the skills and competences to participate in the tender and to carry out the tender works.

To clarify, which data are included in profile of the company the description of it is provided below.

3.3 *Company's profile*

Company's profile data requirements are described in data models, described during e-NVISION project work. The Company Model contains a structured representation of all the valuable information related with a company and needed by other companies in order to make business with it. Such data allow the SMEs to describe themselves in order to have a common view of all the information related with the company.

[3] Not discussed in this scenario.

Figure 4. It shows company's profile data model (based on ontology). The full squares points the simple data type properties and the squares with white vertical dash are representing object properties. Note that not all of them are mandatory, that is, a Company may not have all them described.

This schema model will contain different type of data elements together with their relationships related with the e-NVISION specific business domain and applications, i.e. related with the e-Tender and other processes (Fig. 4). The purpose of these elements is:

- demandsItem. It gives information about the product or service demanded by the company. The range of this property is both the service and the product concepts from the Product/Service ontology.
- hasCompanyCompetenceLevel. It gives information about the competences of the company. The competence level is a concept of the competences ontology.
- hasCompanyExperienceLevel. It gives information about the experience of the company: references, previous projects in which the company has participated, etc.
- hasCompanyRegisteredName. It gives information about the registered name of the company.
- hasCompanyTradingName. It gives information about the trading name of the company.
- hasCompanyVatNumber. It gives information about the VAT number of the company.
- hasIDCode. This ID represents a unique organization identifier. In Slovenia, it is issued on the date

of registration of a business entity into the business register of Slovenia.
- hasCompanyTrustLevel. It gives information about references that help you to trust this company.
- hasCompanyUnit. It gives information about the unit of the company.
- hasContactEmail. It gives information about the email you can use to contact the company.
- hasContactPhone. It gives information about the telephone number you can use to contact the company.
- hasContactFaxNumber. It gives information about the fax number you can use to contact the company.
- hasAddress. It gives information about the complete address of the company including: street, country, region, province, etc.
- hasNumberOfEmployees. It gives information about the number of employees of the company.
- hasActivityCode. It gives information about the code of classification of economic activities of the company.
- hasTurnover. It gives information about the turnover of the company.
- hasCurrency. It gives information about the currency used by the company when doing business.
- hasResponsiblePerson. It gives information about the people in charge of the different issues in the company, i.e., the person responsible for the quality issues, for the construction project development, for the environmental issues, etc.
- hasSubcontractor. It gives information about a subcontractor that has previously worked for this company.
- hasSupplier. It gives information about a supplier that has previously worked for this company.
- hasWebsite. It gives information about the website address of the company.
- providesItem. It gives information about the product or service offered by the company. The range of this property is both the service and the product concepts from the Product/Service ontology.

3.4 *SME registration for CFTP service*

Earlier it was assumed that SME gets automatic tender notifications. To send the notification for registered company it is needed that tender awareness service would be invoked.

Before some tender provider SME (public local developer) will be able to publish the tender it should be registered for CFTP (Fig. 5). Manager of SME fills company data in profile form and sends it to external agent (CFTP service).

In general, user (SME which will provide tender) profiles may have less information since there will be no need for user and tender profile's comparison only for SME identification, authentication and authorization. Therefore it will be enough to have only part of data, described in company's data model.

Figure 5. To be able to publish a tender SME should register first in CFTP service.

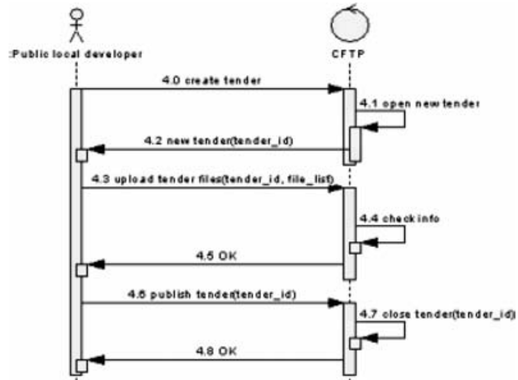

Figure 6. This figure provides new tender creation schema. The company invokes new tender registration activity first. After that CFTP service registers new tender and provides tender identifier. Further company prepares tender data and sends them for approval to CFTP service. After data check company gets confirmation, that new tender is created. When company decides to publish the tender it invokes CFTP service operation.

3.5 *New tender creation*

After company which would like to provide a tender registers itself it may register the tender. Public Administrations will be assisted by the electronic tender systems in the creation of a tender (Fig. 6). Document templates or electronic standard forms shall be used to prepare the tender. All the tender information: objective, location, price, contractor company requirements, technical documents, will be stored using a electronic form, while technical documentation will be uploaded and stored in the tender workspace created for that tender.

3.6 *Tender model*

The Tender Model will contain a structured representation of all the information related with a tender.

Figure 7. It shows Tender data model (based on ontology). The full squares points the simple data type properties and the squares with white vertical dash are representing object properties.

This schema model covers the following information (Fig. 7):

- hasName. It gives information about the name of the tender call.
- hasTenderType. It gives information about the type of tender: construction work, supplies, etc.
- hasTenderMatter. It gives information about the tender matter, which depends on the type of tender. For example if the type of tender is *a* construction work then the tender matter could be a tunnel, a building, electric installations and so on. On the other hand, if the type of tender is supplies then the tender matter could be construction materials, transport material, machinery and so on.
- hasDescription. It gives information about the tender subject that details the tender matter.
- has Appendix. It gives information about applicable administrative clauses and additional documents related with the tender.
- hasDueDate. It gives information about the due date to provide the documentation.
- hasLocation. It gives information about the location of the tender works.
- hasInvestor. It gives information about the investor or the organism that offers the tender.
- hasBudget. It gives information about the budget for the tender, i.e. the maximum price of the tender proposal.
- hasTenderOfficialAnnouncment. It gives information about the Tender Official Announcement (source, year number, etc).
- RequestsConstructionWork. It gives information about the construction works requested in the tender call.
- requestsItem. It gives information about the product or service requested in the tender call.

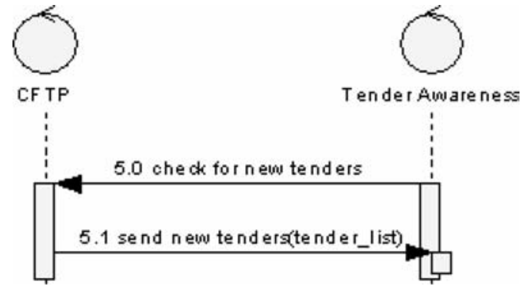

Figure 8. This figure shows the way the tender is published for tender awareness service.

- requestsQualityWork. It gives information about the quality work requested in the tender call.
- requiresEstimate. It gives information about the type of estimate required in the tender call: Sistela, Presto or other tool.
- requiresLegalDocument. It gives information about the legal documents that need to be provided in the tender proposal.

3.7 *The generalization*

Above described activities of current section provides the requirements to ensure the needed state for e-Tendering process. This step could be understood as a creation of infrastructure for tendering workflow. After the companies are registered to tender awareness and tender configurator services, and some SMEs are registered to CFTP and have created new tenders, the real e-tendering process starts.

4 SEND TENDER CALL NOTIFICATION

4.1 *Tender publication*

Once the tender has been created the Tender Service allows the Public Local developer to publish the tender (Fig. 8). This part might be implemented via external Web Service with timer which would refresh tender list time to time.

After tender awareness service gets new tender it compares tenders data with subscribed companies' profiles and looks for most potentially suitable (SME 2 in this case – Fig. 9) project executors and sends notification messages (tender identifier and tender info – the short description of the tender) to them. It can be e-mail, SMS or in other way (SOAP, FTP) sent message which would be caught by some event listener under E-NVISION system.

If the manager, which represents the company (SME 2), after primary tender info review is interested in tender it applies for full tender documentation (for tender file list). Once the SME gets full tender papers the SME configuration task starts.

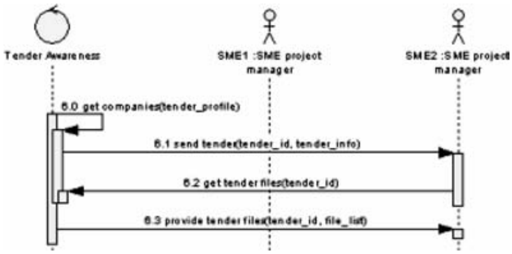

Figure 9. Tender notification schema. Tender awareness service notifies suitable SME abut new tender. The manager in such SME reads the preliminary information about the tender and, if his company is interested in the tender, asks for full version of tender documents.

5 MAKE CONSORTIUM

After SME notified by tender awareness service as potential executor SME decide to compete for tender it could appear situation when such SME (GC – general contractor) is not able to fulfill all described work (for example, the specific type of grass field asked for in the tender for the hockey field, the stands for the athletics track and the swimming pools, for more information look at WP2 D2.1 sub-section 6.2). In this case e-NVISION provides a great opportunity – Tender Configuration service.

Once GC gets full tender documentation it should be reviewed. Next thing is decide if SME will be able to do all tender's tasks by itself or not. In the latter case GC should find some subcontractors. Therefore GC starts consortium configuration[4].

The general view of configuration process (actually it is only sub-process of e-Tender process, but in local meaning tender configuration will be kept as independent process) have such phases (Fig. 10):

– GC invokes tender configuration service (some parameters are sending with).
– Tender configuration (TC) service analyzes (performs tender decomposition to tasks) GC's which tasks should be performed by other SME.
– TC service search for suitable SMEs (by comparing tender profiles part, which is not overlapped by GC profile) and creates primary grouped SMEs list.
– TC service filters SMEs by using specified criteria (trust info, additional info from back-end systems etc.) and creates secondary SMEs list.
– TC service returns secondary list with possible SMEs groups to a GC by invoking negotiation phase.

Further all steps will be described more precisely.

[4] Start of this process is invoked by stating that it is not enough to accomplish tender by itself.

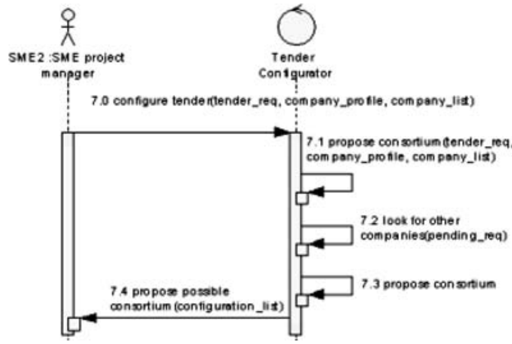

Figure 10. This schema provides the way to crate the Virtual enterprise.

5.1 *Configuration invocation*

This sub-section describes the configuration stage – invocation of service and additional data (required parameters) delivery. At this phase GC sends tender requirements and company's profile for TC service. Such service might be invoked by e-NVISION system.

5.2 *Decomposition*

Decomposition points out the tender division into small works and comparison with GC profile tasks. Tender decomposition goal is to gather works that need to be performed and materials and equipment needed for this construction project and competences of the SMEs. On the other hand, the tender configuration will be in charge of analyzing a tender, identifying the tender matter and according to the tender model decomposing the tender matter in sub-tenders or sub-works that can be carried out by and matched to different profiles of SMEs. The output of this is list of works and tasks which are needed to be implemented by GC partners or sub-contractors.

This service will be in charge also of getting information about possible business partners (suppliers, customers and so on) from the internal information system. This system could be a text file, an spreadsheet file, a relational database or any other kind of data store. This service will be encapsulated as a web service.

The additional data about possible partners SMEs should support possibility connect to external databases (registries).

5.3 *Primary SMEs list*

Primary SMEs list creation covers the way how from tender tasks pick up suitable SMEs and groups it according profile specifics. This way the SME Configuration service provides different alternatives for groups of SMEs that could bid for the tender. The

SME Configuration does not bother on what terms the SMEs bid for the tender, whether as partners or as subcontractors or as a mixture.

5.4 *Secondary SMEs list*

This e-tendering sub-process covers two steps:

- Gathering of additional info for chosen SMEs.
- Creation of secondary SMEs list.

Further both steps will be described in detail.

5.4.1 *Additional info gathering*

During this stage potential SMEs are checked regarding trust, technology and other specific criteria, to find most appropriate companies. Additional info gathering stage is divided in sub-steps. To describe these steps more clearly the list of sequential workflow represents the retrieval of information about the criteria:

1 First GC gets full list of primary SMEs.
2 Further the search in internal database is performed to check if SMEs are in DB list of partners.
   - a) If an entry about the particular SME were found in DB then the required info with criteria values are searched in internal CRM system.
   - b) If particular SME is new for GC and it had no contacts with it at the previous projects, then required criteria values are requested from external web services (for full list of involved web services, please see the following sub-subsection).

3 The criteria values abut each SME from the primary list are gathered and the second step is initiated (please, see sub-sub-section creation of secondary SMEs list).

5.4.2 *The web services used in criteria gathering*

There are four web services providing an additional information about the SME:

1 Trust agent. Trust is crucial during negotiation and cooperation. Therefore, this service checks the trustworthiness of other SMEs based on experience and reputation information. The web service could provide information regarding Company and Manager Identification; Economic and Financial Information that includes commercial, financial and prejudicial reports, modular products, monitoring service...; International Information about Credit reports on companies in other countries and country risk information; Register Services with the information you can need from the Mercantile, Property and Traffic Registers; Sectors statistics, rankings and reports.
2 Agent for prequalification of SME's. This service provides recommendations or references of the products or services offered by an SME. It could be external or internal service.
3 Previous technological references. This External Service will provide information regarding previous technological references of already finished construction works or services provided by SMEs.
   This service is updated with the SMEs backend information and published to the outside world. It could also require a third party (i.e., similar to a search engine) to aggregate (index and cache) this information from different SMEs.
   This Service will use special standardized data models to describe these construction works or services (e.g. technological references) provided by SMEs or any other actor using the e-NVISION platform.
4 Company/Supplier info retrieval. Since not all companies will be members of the e-NVISION, this service will cover two aspects:
   - a) Collecting and updating information from the SMEs that are already registered in the e-NVISION platform.
   - b) Capturing information from newly registered SMEs – new members of the e-NVISION platform.

   This Information Retrieval Service will map the information of these Companies/Suppliers in order to formalize this information in terms of the company data model.

5.4.3 *Creation of secondary SMEs list*

When additional information for SMEs is prepared, then it is possible to create more elaborated list of SMEs (similar to primary SMEs list creation).

5.5 *Return of SMEs list*

The final step of whole process is the return of final SMEs list. Configuration service returns secondary list of chosen (most suitable) SMEs during this step.

6 CONCLUSION

Assuming the time, financial and other efforts required to bid for tender in traditional way it could be stated that suggested e-Tendering scenario implementation would provide more attractive way of participation in tender calls.

Provided solution reduces amount of efforts and required time to prepare and publish the tenders. Electronic tendering will cut down the time between the tender publishing and its delivery for potential participants in tender call.

It is truly that e-tendering scenario solution will reduce the obstacles for small and medium size enterprises to bid for tenders. Provided solution will allow for such companies join and build virtual enterprises regardless the distance between the regions they are located.

Implemented solution will offer the way to increase the possibilities of small and middle size companies to compete in Europe building and construction market on the equal base with large enterprises in this area. Furthermore, looking from the long term perspective e-Tendering will provide possibilities to enhance the participation scope of small and medium enterprises to the global level making the strong basis for e-Business collaboration improvement.

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Restricted to a group specified by the consortium (including the Commission Services) *Technical Annex.* Access through internet: <http://www.e-nvision.org>.

eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

Towards a digitalization of site events: Envisioning eSite business services

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ABSTRACT: This paper presents a solution to enhance communication between construction site actors (e.g.: site foreman) and remote actors (e.g.: design office, project manager, suppliers) of a construction project. It shows the underlying concepts and the preliminary design of tools made to face, as efficiently as possible, and react to unpredictable events that occur on site and which significantly affect the construction schedule planning and generally the project. As these unforeseen events take part in the responsibility of the overall construction project costs, this paper will discuss how to deal with this issue by offering some services in order to provide a better reactivity, adaptation and decision making process. We will present how, by simply logging events, it is for example possible to adapt the schedule on a real-time basis. This approach relies on some graphical user interface applications available on mobile devices, a distributed communication environment with a Service Oriented Architecture, and a construction business oriented ontology which will implement self learning capabilities in the future, based on previous projects experience.

1 ON GOING SITUATION

1.1 *Context description*

Synthesis of figures provided by the French Construction Quality Agency (AQC 2007) reveals major impacts of dysfunction according to the origin of issues in construction project, as shown in Table 1 below:

Indeed, if design stage represents the most important relative construction cost, site incidents take also a worrying importance in the total realization budget of a project.

Implementation is one of the main reasons of construction dysfunctions surely due to the particular context of the construction site:

1) The stage break: change from design stage to realization stage.
2) The involvement of new and various working team and companies coming from different organizations.
3) The isolation of the construction site, with very often the lack of existing infrastructures and network: energy supply and telecommunication.
4) The short and very limited life cycle of the construction site.
5) And the intrinsic frailty of the construction site, due to the lack of protection: exposing site to forecast condition, thievery and vandalism.

Table 1.

Dysfunction origin	% occurrences	% construction cost
Design	14	8
Implementation	81	12
Maintenance	2	3
Other	2	3

In order to complete the overall picture of the situation, we may also mentioned that much information is exchanged on a construction site with a very strong tradition in the oral communication and also a preference for paper-based documents, like for example execution plans and ground plans. Unfortunately some information is lost, or sometimes decisions are taken at short notice or from habit without considering other events or external information suitable for an optimization of the current task or the next tasks.

On the construction site, the work is most of time based on the field know-how experience rather than a formalized process. Presently this approach seems to meet real time feedback requirements on unforeseeable events as a project adapts oneself to the way of things.

In these occasions, the information is rarely real-time recorded: sometimes it is weekly "registered" in the site meeting report although sometimes it can be lost. And the information registered in the site meeting report is not always used to update design and preconstruction documents even in the counting task ("récolement" in French) during the handover phase.

This common practice has a consequence not only on the quality results but also by side effects on:

- maintenance costs,
- construction insurance fares increases,
- delivery delays,
- capitalization of experience.

and finally on the satisfaction of the customer and project team.

1.2 *How can we help?*

In the previous paragraph we presented elements emphasizing the hardship of the execution phase. With the support of figures collected by AQC, we know that implementation is the main cause of the dysfunctions in the construction which are certainly due to the lack of communication between actors of the project. All that makes tough the installation of a "digital assistive system". Though, such system would permit the integration of the construction site into the global project information system in a transparent way.

Thanks to an impressive technological offer going from communication network solutions and device solutions like tablet PC, smart phone etc. the construction site can keep more and more the communication with the outside world. A physical link between the information system (hosting the design information), the project manager, experts, providers, contractors, customers and the construction site is now at our disposal. Communication technology is not anymore a barrier to use advanced and efficient software tools for the concurrent engineering and especially on construction site.

2 BUILDING THE INITIAL SCHEDULE

2.1 *Presentation*

In the construction sector such as in other sectors, after the conception has been done, a first difficulty is to correctly set-up the work planning from day 0, which corresponds to the start of implementation, to the estimated d day, marking the delivery of the final built product.

However, one emphasized difficulty to face in construction is the great number of actors, equipments and materials involved to perform tasks in the process of making one or several buildings, their availability, and the coordination of them during each step.

2.2 *Objectives*

The challenge is to define and plan the most efficient sequence of tasks to perform (during the project implementation: day 0 to d day period) in order to reduce the costs and carry out them with all required resources available on time. This is a projection as we can't predict what will really happen. To achieve this goal, we need to define the main concepts involved in the schedule definition (describing the site activity), and we have to invent some tools or services to help the project manager to handle them in the most efficient way.

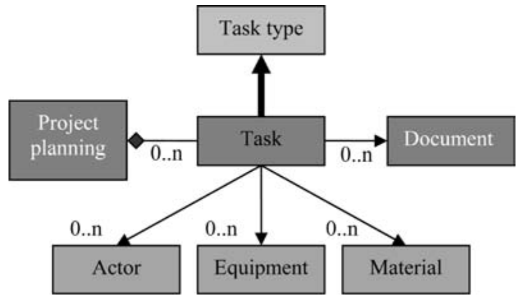

Figure 1. Main concepts in planning elaboration and their association.

2.3 *Main concepts*

Some basic main concepts related to the schedule elaboration work can be defined:

- A task and its task type (e.g.: "Ground floor installation", "Door frame laying", "Indoor masonry", etc);
- An actor: it can be an external company, a service or product provider, an internal or external human resource with a specific skill or not;
- An equipment: it is an internal equipment owned by the company or an equipment rented to an external company; it can also be a piece of equipment: we may own an equipment but we may also need, in the scope of a specific task, a dedicated add-on component required to achieve the task; we will have to borrow, buy or rent this element;
- A material used in the construction process;
- A document: plan, report, review, user guide for an equipment, etc.

The schedule is made of some tasks, each of them belonging to a task type. A task features some properties such as "start time" and "end time" and may be associated to some documents. To be achieved, a task possibly requires some actors, equipments and materials. The following Figure 1 illustrates the links between these concepts (Kubicki 2006):

The great idea is to bring a semantic shared conceptualization in the schedule elaboration, defining some concepts, instances and links holding knowledge. Ordinary planning management tools usually allow the schedule editing in a task-oriented way, forgetting associated concepts and the features/knowledge they hold. Moreover, most of the time, such tools don't include the ability to create knowledge referential data that could be reused project after project.

2.4 *Knowledge referential system*

There is no innovation in defining a schedule management tool as it already exists. However, innovation could be brought in the definition of a knowledge referential system. Such system is divided into two parts:

– First part is project-independent, meaning outside of any particular project but possibly applying on any project: this is the general business knowledge referential system. For instance, in this knowledge, we can record the list of actors able to achieve a task type (e.g. companies C1, C2, C3 and C4 are able to achieve a "roofing laying work" task).
– Second part is dedicated to each project to define either selections or exceptions to the general knowledge set in first part. For instance, in this knowledge, we can set the list of actors selected by the project manager before the start of implementation which could achieve a task type (e.g. companies C1 and C2 are selected to possibly achieve a "roofing laying work" task if we have some tasks of this kind in the schedule).

Generally speaking, the knowledge referential system defines a classification of task types. For each type, it stores a list of links towards all potential required actors, equipments and materials, as well as documents involved. It should help a project manager to answer a question such as: "If we want to do this kind of task, which actors can perform it, using which equipments, requiring which materials, relying on which documents?"

A first service should enable to populate the referential data stored in the system (inside the ontology). This service could be invoked by business experts before (for instance during providers selection stage) or at each stage during construction projects. It should also be called after the end of a project in order to integrate its own knowledge. It can include some financial information to be able to answer to questions such as "How much does this kind of task costs if it is made by this company?", "For this kind of task, we may need such equipment, how much does it cost to rent it? ", "To perform this kind of task, we need materials A, B, C, how much do they cost?", etc.

A second service can be used during schedule making or updating in order to help the project manager to find, for each task he sets (instantiates) in the schedule, which actors, equipments, materials could actually be used for each task. The manager can choose some instances suggested by the referential system or can set up its own data (e.g. the manager selects the company

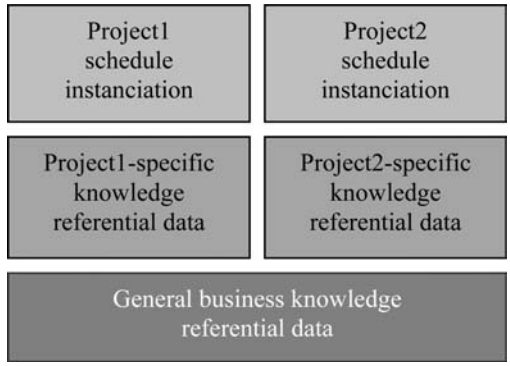

Figure 2. Information levels in schedule concepts.

C2 to achieve a "roofing laying work" task planned on days 101, 102 & 103; he could have choose company C1 also provided by the system, or any other company). Of course the system does not take any decision but is more like a decision-aided tool, providing a list of potential choices.

As a summary, let's say that we have three levels of information as shown in Figure 2. Levels 1 & 2 are defined inside the knowledge referential system as explained in this section; whereas the third level is the actual schedule instantiation of a particular project.

2.5 *Prospecting for new suppliers*

A semantic web-service has been developed by CSTB in the scope of IST e-NVISION project (*A New Vision for the participation of European SMEs in the future e-Business scenario*). This process, called the "TenderConfigurator external web-service", offers several possible consortiums (groups of SMEs) with the skill and competences to participate in a tender and to carry out the tender services, works or required products supply.

This service could optionally be used when creating or updating the construction schedule to search for and find some new suppliers of required services or products. If desired, the project manager can invoke this service to populate the system with a new actor able to satisfy a requirement on a particular task. Moreover, this information can be reused for other projects when it is integrated inside the general business knowledge referential system.

2.6 *Dispatching resources*

A difficulty for project manager is to correctly dispatch and allocate required resources (actors, human resources, equipments . . .), on time, on each task of the construction planning. Moreover, big construction companies often work on several projects at the same time, so they need to perform this management job simultaneously on several planning tables. Another parameter is that resources may be owned by the company (e.g.; trucks, lifting cranes) or may be rented by the company to a supplier. For the project manager, this is a difficult issue to dispatch and allocate resources in the most efficient way, for the best low cost.

To answer this problem, the system must offer and display different views of the schedule information:

- Task view: this view is the one we already know showing sequences of tasks, starting from day 0 and ending on d day. It allows the definition of tasks and their association with some actors, equipments, material and documents, using (or not) the referential knowledge.
- Actor view: this view shows where, when and for how long, each involved actor steps in the construction process, taking into account that the same actor can be involved in some different projects. It could also show where an actor could be used (in which tasks of which projects).
- Equipment view: same as for actors; moreover, it indicates if the equipment belongs to the company or is rented to an external provider.
- Material view: same as for actors except that there is no duration, a material is required on a precise time in the schedule or on a periodic basis.
- Document view: this view shows where (for which task) a document is exploited or modified during the construction process.

These windows present the information with a particular and different point of view. Thanks to this graphical user interface, the project manager can define one or several construction projects planning at the same time and he (or his team) is helped in the process of identifying free available resources that can be allocated to a task inside a particular project, as well as busy resources. Thus, he can optimize the use of each resource.

2.7 *Delivering the schedule*

Nowadays, projects managers elaborate their project schedule and send a copy of the corresponding sub-set of it to each general foreman (on site) or site manager. The sub-set represents the interesting part for the target person who doesn't need the whole planning document.

First innovation, taking place in offices, would be to display the schedule (and its different views, as explained before) to projects managers on a plasma screen instead on a never up-to-date blackboard. It would help them to dispatch and see the availability of each resource. These views will be updated on real-time so the information would be accurate for each manager, including on several distinct projects.

Second innovation, taking place on site, would be to provide a tablet-PC to each site foreman. The central system would implement a service that would automatically send, on a real-time basis, the appropriate and updated part of the planning to each responsible person on site. Thus, schedule information would be dematerialized from the source to the target, stored in a centralized system, and transmitted to the accurate actors on site. To achieve this goal, we should be able to decompose the schedule in sub-parts and set which actors are in charge of each part. Then the system would be able to detect any change on one of this part and send the up-to-date part to the correct recipients.

3 ON SITE ACTIVITY TRACKING

3.1 *Presentation*

In the construction sector, there is often a lack of communication between work teams on site and projects managers (and other work partners), staying in remote offices, who are not always immediately (or not at all) warned of events occurring on site. There is also a lack of activity tracking/recording on site.

3.2 *Objectives*

To enhance this communication and to establish an activity tracking on site, we provide a tablet-PC to each general foreman with a dedicated application.

This application enables the log of a message for each event that occurs on site in a real-time mode, such as an electronic log book. Then, this message is transmitted to be exploited and stored in the central system at the office. It may or may not affect the project schedule. The graphical user interface of this application is easy to use with a lot of predefined event properties and the choice between five main events families to log as described below. Each of them is associated with an object (or concept instance) already defined in the project's schedule.

3.3 *Task event*

A task event is the most common kind of events. When the foreman logs such event in the application, he associates it to an existing task in the master schedule of the project (he can also associate the same event to several tasks). Thanks to this mechanism, he informs the project manager at the office that a task is impacted by an event occurring on the site. This event may counteract the correct execution, on time, of the associated task. It may speed up, cancel or delay the targeted task according to detailed information provided when logging the event.

Here are some examples of task events: a sewerage foundation task can't be performed because of the presence of an unexpected material under the ground; an outdoor finishing carpentry task, which has been started, can not be completed because of bad weather conditions; etc

3.4 *Actor event*

An actor event is logged by the foreman on site when something is happening concerning a company, a service supplier or a human resource. Such event can also be logged by the project manager at the office (and not only on site). Indeed, different people located on different places may have some different information. Thanks to this event, they will share the same information.

Here are some examples of actor events: a skilled resource, in charge of performing indoor masonry, is injured; some unskilled workmen planed on a task are missing (because they have been temporary set on another task); a supplier is late and not able to deliver a service on the required time; a company does not deliver anymore a product we need; etc.

3.5 *Equipment event*

An equipment event is logged when something unexpected occurs on an equipment on site (this equipment may be used to accomplish one or several tasks but it is the system that will check this).

Here are some examples of equipment events: a truck or a lifting crane is out of order; specific equipments have a feature that doesn't fit the requirements to accomplish a task; etc.

3.6 *Material event*

A material event is logged when something happen on a material used on site.

Here are some examples of material events: a bricks delivery doesn't match what was ordered; we haven't ordered enough material for a finisher to perform the required asphalt paving; etc.

3.7 *Document event*

A document event is logged by the foreman when a document has been modified on site and this modification may impact some other tasks. This way, the project manager is immediately informed of any document changes.

4 UPDATING THE SCHEDULE

4.1 *Presentation*

In previous section, we described a service allowing the log – on site – of some events occurring during the construction process. In this section, we focus on the exploitation side describing a possible first service (among others) which analyses these recorded events in order to help the project manager – in the office – to efficiently update, on a real time basis, the project schedule.

4.2 *Objectives*

During initial schedule making, the project manager can not anticipate unforeseen future events that will occur during the construction process. He can have a risk management policy but he can not predict what will really happen, and hazard may significantly impact the work schedule.

The recorded-on-site events will be displayed at the office on a real time basis. The objective of an innovative service would be to propose some possible options/actions of changes to perform on the schedule according to events occurrence. The goal would be to maintain the initial implementation period (day 0 to d day) with the less lateness possible. For the moment, we don't include the financial view in this scope; we only care about achieving the construction project on planned time, delivering the built product to the final client on expected time. We have to invent an innovative service to reach this goal.

4.3 *Retrieving events impacts*

The first step of the process is to find all elements (tasks, actors, equipments, materials, and documents) impacted by each event that occurs on site. It answers the question: "What are the consequences of an event on the elements (objects) belonging to our work schedule?" This step has yet been implemented in the e-NVISION project. For instance:

- If a task event is logged, the process is able to retrieve all the actors, equipments, materials and documents associated to the task referenced by this event.
- If an actor event is logged, the process is able to retrieve all the tasks (present and to come) in which the actor, referenced by this event, is involved. Then, for each of these selected tasks, the process can retrieve all the actors, equipments, materials and documents associated to it (such as for a task event).
- If an equipment or material event is logged, the process is able to retrieve all the tasks (present and to come) in which the equipment or material, referenced by this event, is required or used. Then, for each of these selected tasks, the process can retrieve all the actors, equipments, materials and documents associated to it (such as for a task event).
- If a document event is logged, the process is able to retrieve all the tasks (present and to come) associated to this document. A change in this document may affect the associated task or one of its components. For each of these selected tasks, the process can then retrieve all the actors, equipments, materials and documents associated to it (such as for a task event).

4.4 *Providing a decision-support tool*

The second step of the process is to provide to the project manager some solutions in order to face events, now knowing each event's impacts on schedule components.

To achieve this goal, the process relies on different strategies. Firstly, it tries to maintain an affected task at the same position (same start date and end date) in the schedule, if it is possible, to avoid a chain reaction of updates on following tasks. Secondly, if the task can't be maintained, the process proposes to delay it on time in the most efficient way.

4.4.1 *Maintaining a task*

This can mostly be performed on tasks planned in the future (including a near future). Indeed, for a present task, we may not have enough time to react and find a good solution to maintain it on time, depending on the event's level of gravity.

For instance: if there is a problem on an actor, an equipment or a material who/which is missing, the system will search for a temporary arrangement or a replacement solution:

- Concerning actors: the system will look for an available skilled actor that could fulfill the work. If it is a workman, maybe a similar actor is unused on another close site, or maybe such skilled-person could be find through a temporary work agency that the system could interrogate. If it is a provider, we may find inside the knowledge referential system an alternative provider (previously selected by the project manager or not).
- Concerning equipments: the same search strategy applies. The system will look for an available equipment that could replace the awry one (if need be). This equipment can be found inside the project management company fleet or could be borrowed or rented to an equipment provider.
- Concerning materials: the same search strategy applies. The system will look the use of such material on other future tasks (belonging to this or other projects). We could use this material as an alternative and order some new material for the future tasks that have been temporarily dispossessed.

Such system has to be improved finding some mechanisms able to provide some replacement solutions in order to maintain a task on time. These rely on logged-event features analyzing, semantic schedule information and business referential knowledge database.

4.4.2 *Delaying a task*

According to event information, a task may be delayed on time.

For instance, if bad weather conditions occur today – and if they are forecasted to last for one more day – then the site foreman will log an event. The process will search for tasks, planned to be performed today and tomorrow, which are dependent on good weather condition (e.g. "outdoor finishing carpentry"). As selected tasks can not be started today, neither tomorrow, they must be delayed on time. The system has to find if some replacement tasks (not weather condition dependent) could be switched with the delayed task (e.g. "indoor masonry"). Such new tasks could be performed today and tomorrow instead of them. Of course, before showing this option, the system has to check the availability of required resources (actor, material, equipment ...).

They are many other examples of event logs that could cause a task delaying. The more sophisticated will be search mechanisms and semantic information held in the schedule and in the referential knowledge, the more efficient and accurate will be the options/actions suggestions.

4.5 *Choosing an action*

As we said, the objective of this service is to help – but not to replace – the manager to correct and adapt project(s) schedule(s), as a decision-support tool or business intelligence software. This relies on the ability of the system to incorporate projects knowledge and referential business knowledge, in a more efficient way that a human would do it.

Indeed, the manager may not be aware of the whole project knowledge (e.g.: where/when such actor is required?, where/when such equipment is free or busy?, when do we get some material delivery?, which companies could deliver such material or rent this equipment?,...), so it makes it difficult for him to take the best decision about schedule modification without this kind of service.

The project manager can select an option/action suggested by the system or can do its own change without considering system advices. Next step is to actually update the schedule according to selected option. This modification may impact some other tasks especially when a task is delayed: in this case, some other tasks will also have to be moved which will impact resources. At the end of this update, a new schedule version is released.

4.6 *Delivering the schedule*

As the schedule has been changed, its new version must be provided as soon as possible to appropriate recipients as work is in progress.

On office side, each project manager should see the new schedule either on its personal computer or on a common plasma screen.

On site side, the system would send on the tablet-PC of each foreman the appropriate part of the planning. Thus, planning information would be available as fast as possible to final construction performers, without any paper or oral transmission.

4.7 *Updating resources availability*

Thanks to the software, schedule update implies resources availability real-time updates. This feature should greatly help each project manger to dispatch and see the availability of each resource, including when working on several distinct projects sharing the same resources.

5 REPORTING & LEARNING

5.1 *Presentation*

We previously defined a service to help project managers to adapt schedules on a real-time basis. Of course, there are many other ideas to exploit logged events as explained now. Some services could be developed to provide some useful information to project managers, general contractors, quality controllers and other involved actors as well as the knowledge system itself.

5.2 *Objectives*

The objective of this section is to list and briefly describe some services that could be implemented to process the information stored inside the logged events. They would provide different kinds of reports and self-learning information that could be reused to improve the management of future projects.

5.3 *Follow-up site management*

Gathering site events gives the opportunity to display a real time follow-up of the construction site work progress. Indeed, there is a strong correlation between actors, documents, schedules, devices and materials. This is possible then to identify which task of the schedule is currently running and which resources are in use.

A real time schedule, with a complete up-to-date status of resources (devices, documents, actors and materials) provides stakeholders with daily information of the site progress, and gives more flexibility to companies to step in the project at the more convenient time (Anfosso et al. 2005).

5.4 *Maintaining FIW documentation up-to-date (FIW checking)*

The folder of implemented works (FIW) is due to the client for the hand over of the construction (CERTU 1995). This folder records the contractual documents of the project (building permit, site reports, and so on) and is composed of the final version of executive plans and installed materials. It is the correction of the original design folder faced to concrete realisation.

The future exploitation of the construction requires coherence between the delivered building and its documentation. This is a guarantee for the owner to have relevant information in order to exploit (use, maintain and destroy) the building all along its lifecycle.

Thanks to event logged analysis and cross reference checking with FIW content, item to be potentially collected or changed, in order to provide the last version of the FIW, are underlined. Every issue concerning the accuracy of the executive plans can be notified as well. This new service guarantees the delivery of an accurate and an up-to-date FIW.

5.5 *Quality indicators*

Whereas construction quality indicators mainly focus on disorders found in the built projects, a various number of quality indicators could be observed during and at the end of a construction project thanks to events logged on the construction site.

Information related to the average of delays, failures, affected and unaffected resources, involuntary layoffs etc. could be exploit by the PMC (Project Management Company) in order to optimize the project over all cost and the schedule.

5.6 *Capitalizing on experience*

The idea of this service is to perform a debriefing at the end of each project in order to learn from experience and capitalize from failure (bad experience) and success (good experience). The goal of this service is to improve – project after project – the referential business knowledge stored inside the system.

The system would retrieve each event logged during a construction project and match it with the action that has been taken by the project manager to respond to it (action / reaction).

There are different steps in the implementation of such service from the easiest one to the most sophisticated one.

For instance, in a first step, the system could learn and collect information about the efficiency of each involved actor (provider, supplier, human resource), this could also be done on equipments. It could help a project manager find the best actors and resources answering to questions like:

- Can we trust this company for this kind of task?
- Can we rely on this material provider concerning delivery delay and/or quality?
- Which company is able to provide us the best human resources?
- Did we find an alternative supplier when our regular supplier was not able to satisfy our order request?
- Can somebody repair one of my equipment when it breaks? Or maybe a company could rent it to me?
- Is there a document explaining how to proceed with this task or with this equipment etc.

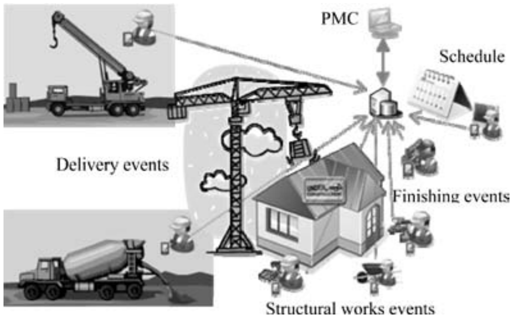

Figure 3. Global view of eSite events collect.

This service should help to improve efficiency in the realisation of future construction projects.

6 TECHNOLOGICAL OVERVIEW

6.1 *Presentation*

The discussed solution features a distributed environment with some distinct remote applications and users. As shown below, aside of the type of task (delivery, structural works, finishing...), and construction site stakeholders (plumber, carpenter, house painter, mason...), events are logged to the eSite back-office.

Technological implementation relies on three main components:

– Ontology,
– Semantic web services,
– GUI client applications.

6.2 *Ontology*

Ontologies bring semantic technology. They are representations of a set of concepts within a domain and the relationships between these concepts (Lima et al. 2003). For our concern, we deal with construction business domain. The main motivation behind ontologies is that they allow for sharing and reuse of knowledge in computational form. Ontologies define a common vocabulary to share information in a domain. They include machine-interpretable definitions of basic concepts and relations among them. As we are in a distributed environment, semantic technology plays an important role in the definition and the exchange of knowledge among distinct systems, applications and actors.

For this project, the ontology stores the concepts mentioned in this document (at least). It should hold the business referential knowledge, projects-specific knowledge, and of course all the data (instances) dealing with the schedule and task concepts. So the ontology is also used as a persistent device to record and store some concepts instances. It behaves such as a database, except it doesn't record rows but "objects" (concepts instances) which have a semantic meaning.

As in the e-NVISION project (e-NVISION 2008), the ontology is implemented using OWL: Web Ontology Language.

6.3 *Semantic web services*

Web services are programs (processes) that are accessible over the web. They can be invoked by the remote applications of the system (on site, at the office). The set of services constitutes the back-office of the system in a SOA (Service Oriented Architecture) approach; high-level exposed services rely on a composition of low-level private services (Charvier & Bourdeau 2008). Semantic web services allow the use of semantic vocabulary defined in the ontology (e-NVISION 2008). They are the only software components that can access to the ontology.

We can distinguish two kinds of services:

– Internal web services are services exposed by the system, such as the service to log an event, the service to manage the schedule, the service to obtain potential options to deal with an occurred event... They are in the scope of our implementation work.
– External web services are services provided by a third "foreign" system, such as the Tender Configurator service (e-NVISION 2008), which searches for potential suppliers of a product or a service, and which allow us to populate the business referential system (for instance).

6.4 *GUI client applications*

The system provides two distinct applications which both rely on the SOA environment, that is to say on semantic web services defined in the back-office:

– First application (on site): we provide to the foreman a tablet-PC (s. Figure 4), with a dedicated application allowing the log of some events and the schedule display. This application should be as easy to use as possible with a lot of predefined field and easy human-machine interactions.
– Second application (at the office): we provide an application to project managers in order for them to be able to handle schedules, tasks, actors, equipments, materials and documents (through dedicated views), as well as to respond to events, as described in this document. We could imagine having not only a regular application on personal computers, but also a schedule display on a big screen (like plasma or wall screen) seen by the whole office. A future feature would be to directly interact with this screen thanks to a human-oriented pointing device (such as in the Wii video game console).

Figure 4. Tablet PC used by a foreman on the construction site.

7 BUSINESS BENEFITS AND PERSPECTIVES

7.1 *Business benefits*

During the erection phase, the construction site becomes the nerve centre of the project and gathers a huge quantity of useful information ready for the actors involved in the project, either mobile or not, either main contractor or subcontractor, and at the same time the information capitalized in this phase is all-important for the maintenance phase of the building until its demolition. Taking in account construction site events can have efficient impact not only the execution, but also on the handover and the maintenance stage the electronic aided collect of site events is going to provide information which is usually lost on the construction site.

Thanks to the use of semantics approach and especially business oriented ontology, analysis of events provides efficient services for business actors since events are strongly correlated with resources of the project like actors, documents, schedules, devices, materials..., and presumably the result of the project, its realization cost and its over-all quality.

Hereunder, we present the benefit of the log event tool for different construction activities and the added-value to make use of such a tool at the different stages of a construction project.

7.1.1 *Preliminary, design stages*

Construction project activity	Benefits
Capitalization of the experience	Implement a knowledge (history) database of projects *Beneficiary: design company, customer, PMC, SME, delivery and procurement companies*

7.1.2 *Execution stage*

Construction project activity	Benefits
Unattended event management	Create immediate association between events task, actors and resources. *Beneficiary: PMC*
Planning management	Optimize task and actor execution *Beneficiary: PMC and SME*
Continuity of team site works	Improve the transmission of information between site actors *Beneficiary: SME, site team members*
Site work follow-up	Enhance site stock management and availability of resources (material, equipment, device, storage area, man power...) *Beneficiary: SME, delivery and procurement companies*
Process of delivery and procurement	Optimize delivery planning for delivery and procurement companies *Beneficiary: delivery and procurement companies*

7.1.3 *Hand over and maintenance stages*

Construction project activity	Benefits
Building delivery to the customer	Improve quality of the built "product" and limit delivery delay *Beneficiary: customer and all contributors to the construction project*
Building delivery to the operator	Improve coherence of the built "product" and the documentation related to the building delivered. *Beneficiary: Operator and all contributors to the construction project*
Planning management	Contribute to the project deadline *Beneficiary: Customer*
Maintenance operation	Pull down maintenance costs by providing traceability of "built" or "integrated" products and realization i.e. additional information for the maintenance/exploitation of the construction. Can be helpful for risk prevention/inspection and also consequently can have an impact on insurance rates pushing down *Beneficiary: customer and maintenance operator or construction companies, insurances*

7.2 *Perspectives: what is next?*

From a research and development point of view, the implementation of dedicated-business ontology becomes a priority in order to deliver efficient (web-) services. The mechanism to automatically feed ontology based on experienced projects is essential in order to avoid fastidious and manual ontology updating.

On a business point of view, a new type of job and activity appears on the horizon BOP: Business Ontology Providers. This activity will aim at providing tailored ontologies for different type of project taking on account specificities such as:

- Size of the project,
- Application domain of the construction,
- Regulation related to the domain,
- Business model of the project,

etc.

8 CONCLUSION

Integration of ambient technology on construction sites faces more cultural, organizational or economical brakes than technical limitations or weaknesses. Mentalities and practices will evolve in the construction sector mainly if economical profitability and viability of such tools to enhance the process is shown, and if actors find day to day benefits to use it.

Whatever is the role of an actor involved in a construction project, education is probably also a key point: why should we pay to deploy these technologies (study, implementation) if we don't understand the benefit?

The business benefit of this approach is obvious since it contributes to enhance the communication between construction actors, manage the respect of time milestones in tasks implementation, reduce disorder numbers and finally improve the overall quality of the built construction.

The next step of this study will be the realization of a real efficient prototype in order to demonstrate the pertinence of such services to the business construction community.

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eWork and eBusiness in Architecture, Engineering and Construction – Zarli & Scherer (eds)

e-Quality & e-Site – immediate tangible benefits for a building and construction sector SME

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ABSTRACT: Web presence, web trading, electronic business document exchange – all these subjects are of only limited use to micro, small, or medium sized enterprises (SMEs) working in the building and construction sector. The volume and the impact of such interactions or transactions in general is very low when compared to an enterprise's daily work tasks. The pay-offs of carrying out these operations electronically in the near future – especially when most of the general supply chain and most business partners are not using these means – can easily be dismissed as insignificant. But there is more than just commerce and business document exchange between companies. Document management systems, on-line and up-to-date documentation, automated event notifications, auditing, etc.: these aspects of "e" technologies present a B&C SME with tangible benefits which are immediately applicable. The identification and presentation of these benefits is the objective of the article: what are they, where is their impact, what changes do they require, what investments do they require?

1 INTRODUCTION

The e-NVISION project describes its objectives as the development and validation of an e-Business platform enabling Building and Construction small and medium enterprises (SMEs) to model and adapt particular business scenarios; to integrate all their enterprise applications and to incorporate legal, economical, social, and cultural services, with the final goal of facilitating their participation in the Future European e-Business Scenario.

In order to achieve these objectives, a consortium was formed consisting of an international mixture of research institutions, ICT developers, consultancies, a university, and, most importantly, several cluster organisations of building and construction (B&C) SMEs and four B&C SMEs companies. The e-NVISION consortium used this multidisciplinary knowledge closely combined with the day-to-day experience of the business experts working at the B&C companies in order to identify, analyse, and generalise 12 business processes occurring daily in the B&C sector. During this period 14 data models, 17 external services, 12 integration services, and 6 ontologies were identified. Based on this information and its internal expertise and experience, the Consortium then tried to identify the future developments of 4 of these business processes and to discover how – using various technological and sociological means – it can help the B&C SMEs participate in them. In the end, the resulting scenarios were confirmed through end-user validation and technological testing.

2 CURRENT STATE OF ICT ADOPTION IN THE B&C SECTOR

During the analytical phase of the project the low level of use of ICT technology in the management of business processes and in working practices in general within the B&C sector became apparent. For a team of specialists from various fields it was easy to identify several ICT technologies which could lead to immediate tangible benefits for the SMEs applying them. Also apparent were the deficiencies present in the B&C sector which seriously limit the possibility of applying many of them or at best diminish their effectiveness. According to e-Business Watch, in terms of ICT uptake and e-Business deployment, the construction sector today is characterised by:

- Highly fragmented ICT usage;
- A multitude of standards, technical specifications, labels, and certification marks, as well as diversity in local, regional, and national regulations;
- Low adoption and integration of relevant ICT in most business processes, especially by SMEs.

These business processes are often characterised by communication and knowledge sharing based on personal or telephone contact;
– Many remote and mobile work processes;
– Many small-sized companies which are typically either organisers of projects and project flows or suppliers to larger project-managing companies, with different ICT requirements.

In the real world this was translated into the following: most SMEs have no backend available to support decision making software; the sector exhibits high resistance to new ICT technology; there are almost no ICT support personnel within the companies, ICT knowledge is scarce and companies have no ICT budget; B&C companies have no common language (no standardisation/vocabulary/taxonomy).

3 RATIONALE

Today most discussions on e-business revolve around web presence, electronic commerce, and electronic business operations – web trading and electronic business document exchange. Unfortunately all these subjects are only of limited use to a micro, small, or medium sized enterprise (SME) working in the building and construction sector. The volume and the impacts of such interactions or transactions in general is very low when compared to SMEs' daily work tasks. The pay-offs of carrying out these operations electronically in the near future – especially when most of the general supply chain and most business partners are not using these means – can easily be dismissed as insignificant and not worth the effort by most B&C SMEs. But there is more to the "e" words than just commerce and business document exchange between companies. The concepts of document management systems, on-line up-to-date documentation, document change notifications and propagation, automated event notifications, centralised logging and auditing, and formal documentation rules enforcement, are just some of the technologies that can be applied without much effort to the daily routine at a construction site. These less publicised aspects of "e" technologies and working practices present a B&C SME with several tangible benefits which are immediately applicable.

Research has identified the following general problems of construction supply chains (Vrijhoef 1998, 2001):

– the client/design interface: difficulties in finding out a client's wishes, changes in the client's wishes, long procedures for discussing changes,
– the design/engineering interface: incorrect documents, design changes, extended wait for the architect's approval or design changes,
– engineering/purchasing & preparation interface: inaccurate data, engineering drawings not fitting the use,
– purchasing & preparation/suppliers interface and purchase & preparation/subcontractors interface: inaccurate data, information needs not met, adversarial bargaining, and other changes,
– suppliers/subcontractors interface and suppliers/site interface: deliveries not in conformity with planning, wrong and defective deliveries, long storage periods, awkward packing, large shipments,
– subcontractors/site interface: subcontracted work not delivered according to the main design, contract, and planning,
– site/completion of building interface: problematic completion due to quality problems,
– completion of building/occupation interface: unresolved quality problems, delayed occupation due to late completion,
– purchasing & preparation/site interface: inaccurate data, information needs not met, unrealistic planning.

A sound generalisation of the identified problems would be that communication – either in the form of the information transfer (data/documents/plans) or information loss (not up-to-date, no common reference, incomplete overview, simply lost) forms an important part of the problems faced.

Also significant is the fact that B&C production is project based, which most of the time means that participants do not form a coherent and aligned community. Since every project is also a one of a kind production, participants encounter numerous unpredicted events and situations, which again will amplify the information transfer problem. This is echoed in the description of three of the main peculiarities of the B&C sector according to Ruben Vrijhoef and Lauri Koskela:

– Site production: Production in construction is always locally bound and dependent on factors such as soil and weather conditions;
– One-of-a-kind production and;
– Temporary organisation.

From the identified processes, the e-NVISION consortium has selected two scenarios which are present mostly in the execution phase of the problems discussed above – "e-Site" and "e-Quality".

The "e-Site" scenario deals with changes and events in construction works – at the building site. The problem which "e-Site" addresses is the communication issue: nowadays, when there is a change in construction works, the affected participants (subcontractors, suppliers) are sometimes not aware of the change until it is too late to react. The "e-Site" is broken down into several sub-scenarios or sub-processes, of which the following are important in the context of this article:

- Scheduling – covers the scheduling and monitoring of all construction work, including deliveries of equipment and material.
- Supervision of work carried out done by the general designer (i.e. the author's supervision), the supervision and control of work by the PMC or independent inspectors employed by the investor and the execution of the changes.
- Documentation management, which includes construction site documents management as well as design documentation and correspondence management.

"E-Quality" is not a separate e-NVISION scenario. Instead, it can be described as the effect of "e-enabling" the business processes. With digitalisation comes order – stricter rules adherence, transparency, accountability, and up-to-date documentation and workflows. E-Quality is usually described within the e-NVISION community as part of or a result of the other scenarios. It is focused in two main areas: documents and their management, and the organisation of all information and data collected during task execution according to the work specification and in compliance with the standards. The e-NVISION e-Quality model offers a structured/controlled system to collect and check the quality through the different steps of the project using the "Final Documentation" structuring. For instance, the e-NVISION collaborative server can collect documents using workflow mechanisms. The collecting is done all along the project path since there is a strong relation between the different stages of the project and the documentation available or required for each stage. There is also a strong correlation between site work "modifications" and design documentation. The solution provides an interactive system to remind SMEs, providers, and other actors involved in the project to deliver the latest version of their documentation each time the system detects an event (a new stage, a new official document delivered, a new site work modification, etc.). The workflow defines the steps of the validation process for the document. These "follow-ups" ensure that 100% of documents are collected, valid, and up-to-date.

It is natural that the concepts present in the sub-scenarios of "e-Quality" and "e-Site" feature some of the easiest practices that can be adopted by B&C SMEs and result in potentially high pay-offs and return on investments. We must stress that this article will not present a complete list of the benefits in daily operations that the e-enablement of the B&C company would result in. Within the article we endeavour to identify and argue for good starting points that can be implemented in the near future and which provide visible returns, especially at a project level of cooperation.

4 GOALS

The e-Site and e-Quality mechanisms are presented together and in the same section intentionally, as the methods to provide the former automatically support the latter. Virtually all of the tangible benefits presented here result in:

- higher quality of work,
- higher quality of documentation,
- improved access to information in an easy, reliable, and timely manner,
- improvement of the situational overview,
- better tracking and accountability (in a paper-based system, lost documents may never be recovered),
- better efficiency and productivity,
- harmonisation and standardisation of procedures,
- information and knowledge sharing,
- decreased response times when encountering expected and – most importantly – unexpected situations,
- the elimination of an unwanted paper trail (which can also lead to confusion resulting in out-dated information being used).

Some of the simplest instruments employed in the "e-Site" are a centralised documentation repository and a centralised diary - event tracking and logging. Even these two simple instruments directly translate into all of benefits enumerated above.

5 SOLUTIONS

The (software) solutions and working practices presented below follow the following requirements: they suggest software available under acceptable licensing terms and provided free of charge, the infrastructure requirements in financial terms are low, they only use technological means available today – now, solutions that are in use and are known to work, they run in Windows and Linux environments and at least one member of the e-NVISION consortium has had some positive experience with it. It is important to note that implementing any of these solutions requires installation and configuration – the cost of these services cannot be predicted. An equally important warning is that an effort to provide high capacity and highly reliable services will double or triple the infrastructure costs. But for non-mission-critical usage and under loads expected for an average construction project, the capacity of simple solutions with moderate infrastructure should be enough. This means that a contemporary desktop PC running a free or commercial desktop operating system can serve as the server for the described applications. Of course, for applications using or providing internet services, internet connectivity is a requirement.

5.1 *Centralised tracking and event logging, event information propagation*

Due to the proliferation of GSM phones capable of SMS messaging, it is realistic to expect that most workers at the site are equipped with one. By providing means to signal events or send notifications to the coordinating centre using SMS messages we can provide a functional situational overview and a form of the site log. The options available are:

- The worker sends an SMS with a predefined keyword when a certain event occurs or some task is completed.
- The coordination centre sends a worker a task notification or a progress status inquiry. The worker simply replies to the SMS by quoting the original message.

In both cases the coordination centre will receive a message with information from a recognised phone number. This allows it to recognise the worker and to validate the origin of the message.

The received messages provide the coordination centre with overview information, however it would be natural to presume that based on the content of the notification, further action is initiated, the schedule is amended, and appropriate notifications (using SMS messaging or some other means) are sent to the affected parties.

5.1.1 *Manual operation compared to the e-NVISION future*

In the e-NVISION system a special integration semantic service is in charge of deducing the effects of such event notification and determines whom to notify as the result. It interacts with the central (construction project) scheduling service in order to deduce the "context" part of the information – the responsible and affected people, organisations, tasks, and documents. When necessary, it will also use the human interaction service to gather missing information and responses from people. Since all activity passes through the e-NVISION system, it is a simple task to provide any type of overview required – chronological diaries as in the case of the site log, or snapshots providing up-to-date situational overviews.

On the other hand, a system with a human operator can perform similar tasks, but only within a less advanced environment.

5.1.2 *Software*

The main part of such a communication system is the GSM/SMS integration server and phones. The main functionality required is the capability to receive and send SMS messages without human interaction. Several low cost Nokia phones work well in combination with the daemon (server) component of the "Gammu" software tools. This solution does not provide a user interface for the management of SMS messages, however it allows for a high degree of integration using very simple means, as individual messages can be stored as files on a disk or as records in a database.

5.1.3 *Document management, up-to-date documentation, changes in documentation propagation, auditing, document standardisation*

It is safe to assume that the personnel working with documents and plans have access to a portable or desktop computer. Therefore, web-based access to documentation or the usage of specialised tools is possible.

ICT developers are well aware of the technologies used for document management and versioning. Several such tools are suitable for B&C SME needs as well. The capabilities of most document (source code) version control software and document management software are:

- Document versioning (the up-to-date version is always visible, and any previous versions are retrievable);
- Access Control – Security policy enforcement (only authorised personnel can view, add, or modify specific documents);
- Event notification and subscription (notification of a document change – using email, SMS, etc.);
- Enforcing the document lifecycle (the system can wait for a specific person – for instance an architect – to approve the document before it becomes final and other users can access it; it is also possible to mark documents as obsolete and keep them for reference only);
- Auditing (every person who has seen or changed the document is recorded);
- Document validation (some document may have to pass certain requirements – content has to be validated, it has to be named suitably, it has to pass virus checking, it has to be digitally signed, etc.);
- Documents can be locked because they are being changed (in the editing process) so the rest of the participants know that it is being changed;
- Faster access to information – they provide a web interface as well as specialised desktop tools for easier integration with other software (content creators).

5.1.4 *Manual operation compared to the e-NVISION future*

In the e-NVISION system two semantic services are in charge of document management and deducing the effects or requirements of the document. The first service performs basic document management functions, whereas the second one analyses changes in the documents in combination with the schedule. This allows e-NVISION to know when to expect or request certain documents, which person is responsible for a specific document, and whom to notify when a change occurs. In combination with a capable document management backend, it is able to provide all of the functionality described above.

With a more primitive solution, the information regarding who is responsible for which document and whom to notify upon any change is a manual configuration process – a list of users and corresponding documents and directories must be statically defined. However, it is possible to manage most of the projects and requirements in this manner.

5.1.5 *Software*

There are several suitable solutions. Two of the most common ones are a CVS/CVSNT server combined with TortoiseCVS client software and a Subversion (SVN) server combined with TortoiseSVN client software.

5.2 *Accelerating workflows and documentation exchange, and trust*

As we try to implement the digital exchange of documents, we meet with the usual problems of e-commerce, albeit in a slightly different manner. Some of the documents – for example design plans – have legal, financial, and safety implications. Therefore, it is imperative to the business process to know that the documents were produced or modified by authorized personnel, when they were produced, and who approved them. As the main purpose of this article is to suggest the practical means to apply, it will not elaborate on the theory and capabilities of digital certificates and their possibilities. We will, however, try to present some of the common issues and suggest some workarounds.

One common dilemma is the legal implications of using digital signatures. This might appear less of an issue in countries like Slovenia or Belgium with appropriate legislation, but local legislation does not solve the issues of cross-border differences and incompatibilities. Efforts such as the "Porvoo Group" have been trying since early 2002 to address the topic of electronic identity (eID) interoperability in Europe, but progress has been slow due to the diversity of national solutions. Without eID interoperability it is hard even to discuss internationally legally binding electronic signatures and therefore documents. As a possible remedy, if it is legally acceptable in local practice, we can list the certificates used in the contract governing mutual obligations between the contractors, together with, or as a part of, their communication protocol.

Another issue is presented by the logistical nightmare that certificates might present to the organization – i.e. what happens if the person "forgets" the certificate (smart-card) at home or the certificate is compromised, etc. As digital certificates are becoming more and more a part of public life, this issue is diminishing in importance. For now using only a limited number of digital certificates for key operations only is probably the best solution.

Third dilemma is the software complexity or the lack of tools. Here the situation has changed drastically in the last couple of years. As presented later in the document, tools are available. The most important milestone is the almost universal ability to present digitally signed documents on users' desktops. Firstly, most of the email client software present on users' desktops is capable of showing and validating a digitally signed message (S/MIME) – which automatically extends to any attached document sent with this message. Secondly, PDF documents are now almost universally accepted – and are now the ISO 32000 standard (PDF specification version 1.7). Free PDF viewers are capable of showing and validating digital signatures of the content and can as well present in electronic format almost any document that can be printed on paper. Similar capabilities are present in most common word processors as well. For documents that do not support built-in means for a digital signature, a separate file with a digital signature (a detached signature) can be used. The e-NVISION consortium suggests using PDF files as a preferred document exchange format. Even if there are other technological alternatives available – DjVu, XPS, just to name a few – none is common.

One of the most important places for using digitally signed documents within the e-NVISION e-Site and e-Quality scenarios is in the documentation management system. The benefits can easily be illustrated by the following two – out of many possible – business rules that we can apply:

- Any document of the type "change in design plan" has to be accompanied by a digitally signed consent form from the responsible architect.
- Any report on on-site quality testing has to be digitally signed by the responsible person.

5.2.1 *Manual operation compared to the e-NVISION future*

In the e-NVISION system, the services described in the previous chapters use digital signatures as an integral part of their workflow management.

Based in the process descriptions, they deduce the responsibilities – who can do what – and what the security requirements are – which documents have to be signed – and enforce them.

5.2.2 *Software*

There are many PDF document creation software solutions available. For Microsoft Windows users, PDFCreator (Ghostscript front-end) presents one of the most common free solutions used. On other platforms Ghostscript is the most common PDF creation software. In combination with the PDF file format, the cross-platform PortableSigner tool might prove useful. For ICT developers iText (Java) and iTextSharp (.NET) are usable references when working with PDF content. For general digital signature operations, OpenSSL is the point of reference. For digital timestamping, used to determine when the document was created, signed or last changed, OpenTSA has been used successfully.

For issuing one's own certificates, the XCA certificate authority has proven useful. ICT departments managing Windows servers will find the built-in solution a very capable one.

The most common viewer for PDF documents is Adobe Acrobat Reader, which is the recommended choice of the e-NVISION consortium.

6 CONCLUSION

e-NVISION provides many high-level, reasoning-capable services, which aim to transform the way some construction processes are carried out today in a more efficient, orderly, and predictable manner. It also introduces new ideas, actors, and ways of conducting business in the B&C sector. The e-NVISION scenarios in such advanced form require a certain level of ICT and cultural maturity. It is impossible to plan and envision future interactions without designing them with such elements. Doing otherwise would not allow and promote growth and new ways of conducting business. Such an imperfect solution would also quickly become technologically obsolete.

The problems e-NVISION seeks to address and the processes it tries to optimize are present in the B&C sector today. Some basic concepts identified and used within the e-NVISON scenarios in order to optimize processes can also be applied to SME operations today.

With two simple instruments, a centralised documentation repository and centralised event tracking and logging, we can alleviate one of the crucial problems in the execution phase of the building and construction process – communication – either in the form of information transfer (data/documents/plans) or information loss (not up-to-date, no common reference, incomplete overview, simply lost). By doing so we also positively affect the quality. With digitalisation comes order – stricter rules adherence, and the transparency, accountability, and up-to-date character of documentation and workflows – all of which result in higher quality. In the end, everything translates into efficiency and reduces costs.

There are several software solutions available to provide an SME or a group of SMEs with these tools. Some of them are available under acceptable licensing terms and are provided free of charge. They have low infrastructure requirements in financial terms, they only use technological means available today, the solutions are known to work, and they run in Windows and Linux environments.

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DISCLAIMER

This paper reflects the authors' view and the Commission is not liable for any use that may be made of the information contained therein.

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Human interaction implementation in workflow of construction & building SMEs

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ABSTRACT: The objective of this article is to analyze the needs of Human Interaction in the BPEL process implementing typical business processes of Construction and Building SMEs, to describe challenges of possible implementation, our selected approach and potential problems of implementation of full human participation. It should help to design further implementations in Human Interaction for BPEL for SMEs regardless of vertical industry.

1 INTRODUCTION

1.1 *Reasoning*

By performing external and integral business processes the need for human interaction may appear. In the way of complex business workflows some non-automated decisions (validation of non-computable information and decision-making) may be required. Responsible persons (such as managers, accountants etc.) may need to perform some allocated tasks or (such has business administrators) take decisions in particular workflow situations (elapsed time for response without any answer, specific error handling etc.).

For long-running processes the success of its further steps is crucial because of the already spent time, other resources and gathered information. In such cases the human interaction involvement is necessary. Moreover, the need for notifying responsible human may arise during the e-business process too. Therefore, this area requires attention and certain solutions should be considered.

In general, human interaction is needed when:

– The running business process workflow is too complex and some non-automated decisions (validation of non-computable information and decision-making) are required.
– Unexpected problems appear (elapsed time for response without any answer, specific error handling is required etc.).
– The process is long-running and success of its further steps is crucial because of the already spent time, other resources and gathered information.

2 HUMAN INTERACTION

2.1 *Principal needs*

There are basic actions which humans may need to perform externally or internally in an SME (those are also the main objectives of human interaction implementation):

1. Initiating a process. This action is more or less simple. The user uses some form and submits it. Such initiation could be done also by invocation of some service (or action) by clicking on a particular link or button, sending an e-mail message.
2. Participating (performing specific task) in the process. This action is one of the most intended to be used in processes. It is also the most complex one.
3. Being notified by a message if a particular event occurs in the process. This way of human-interaction is the simplest one. The responsible user (manager, reviewer or approver) receives a notification about an event. One of the differences between the 2nd and the 3rd actions is that the latter could be performed asynchronously without suspending the whole process.

From the e-NVISION point of view, the most important and difficult to implement is the second type of action (full human participation in the process).

2.2 *Possible ways*

In discovery of possible ways for human interaction implementation the research work in human interaction implementation opportunities in e-Business

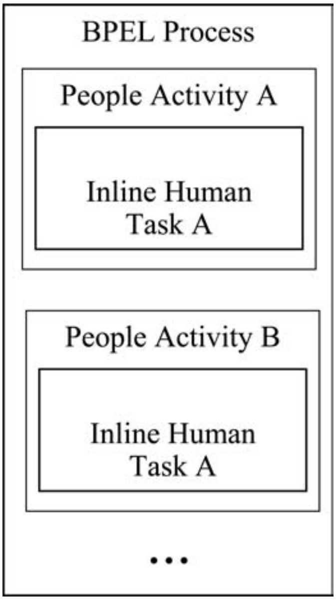

Figure 1. This schema provides the way of possible human interaction implementation when the human task implementations are placed within the people activity block.

flows was performed. Therefore, the most current literature related with BPEL, BPEL4People and WS-HumanTask were analyzed. Moreover, the necessity of analysis of SMEs needs was identified and their requirements were gathered.

Finally, the available ways for human interaction implementation were discovered. The solution was a new BPEL activity type called people activity. It is a basic activity realized by an action performed by a human being. Therefore, the actor of a people activity is determined by a people link. There are four possible ways (task actions) to implement human interaction by BPEL:

1. The first possible solution for human interaction, using people activities, is to describe all required functionality inside the BPEL process inside the people activity description. In this way whole implementation part is located in one place (Figure 1). Unfortunately, such solution has some disadvantages. The main drawback is that the use of the task is limited to the people activity encompassing it. For each people activity element with the same human task is necessary to describe it once again.
2. Second possibility to implement human interaction is to define a task as a top-level element inside the BPEL process description (Figure 2). In this case, the same task can be used many times within more than one people activities. This fact is significant from a reuse point of view. Such BPEL4People processes, with the tasks described not inside the people activities, are portable among BPEL engines that implement BPEL4People. This also holds true for notifications.

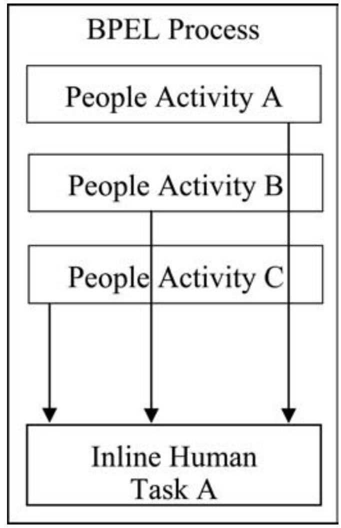

Figure 2. This schema provides the way of possible human interaction implementation when the human task implementation is placed separately from the people activity.

3. More distributed way of possible human task implementation is use of a standalone task within the same local environment, which would be accessible without the specification of a callable web services interface on the task (Figure 3). However, the task invocation implementation is particular for each invocation place.
   This way of human interaction implementation is similar to second one (Figure 2), except that the task is described separately of the BPEL process. Therefore, such implementation of the task reduces the possibility to use BPEL process context in the task.
4. One more possible way is to use of a standalone task from a different environment. The major difference when compared with 3rd presented possibilities is that the task has a web services callable interface, which is invoked using web services protocols. In addition, the WS-HumanTask coordination protocol is used to communicate between process and task. Using this mechanism, state changes are propagated between task and process activity, and the process can perform life cycle operations on the task, such as terminating it. BPEL4People processes that use tasks in this way are portable across different BPEL engines that implement BPEL4People. They are interoperable, assuming that both the process infrastructures and the task

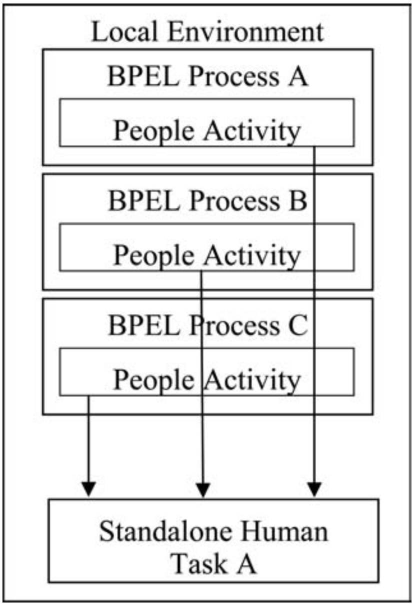

Figure 3. This schema provides the way of possible human interaction implementation with the stand alone human task implementation separately of BPEL process and within of local environment.

infrastructures implement the coordination protocol. In case of notifications a simplified protocol is used (Figure 4).

3 IMPLEMENTATION

3.1 *Solution*

Taking into account the aforementioned notes and possible human interaction implementation ways, it was decided that the 4th possible implementation (standalone human action with callable WSDL interface) is the most preferable one.

The main reason for such a choice was its similarity to a web service. The e-NVISION platform is intended to communicate with web services. Therefore, this area is more researched and it would require fewer efforts to implement. It would also be beneficial to have stand-alone human interaction implementation. Such decision would provide more flexibility. Moreover, it would be well aligned to general view of the project's solutions (communication with web services) and would not make the project much more complex.

3.2 *Solution problems*

However, couple problems were faced.

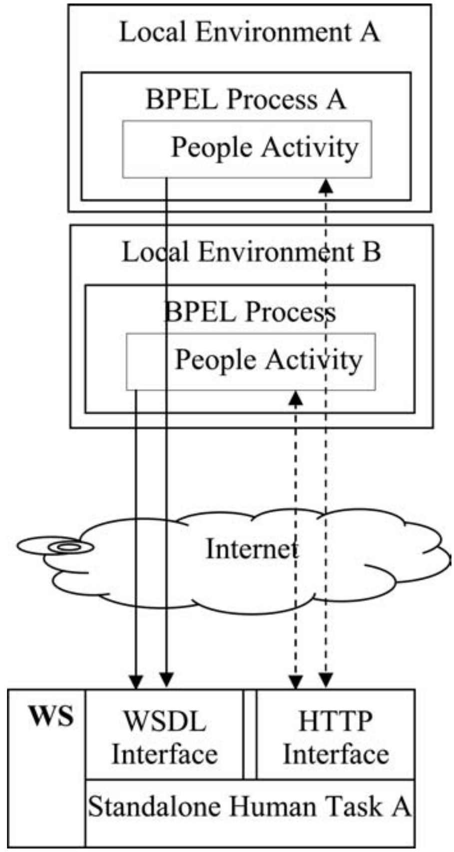

Figure 4. It describes the schema of human interaction implementation as a web service accessible via web services collaboration protocols.

3.2.1 *BPEL generics*

BPEL by itself is not intended to implement human actions. Generally, BPEL is a business process execution language and, in fact, describes automated business process execution. It ensures automated synchronous and asynchronous web services calls. Unfortunately it does not have any people activity elements inside (not BPEL4People).

3.2.2 *BPEL4People implementation availability*

BPEL4People is a standard for human interaction implementation in BPEL. At the moment of picking the technology for human interaction not many implementations were discovered. In fact, only one ActiveBPEL provided BPEL execution engine was supporting human activities. Unfortunately such tool at that moment had no free of charge editor. Also rest part of the BPEL implementation was developed under NetBeans editor with OpenESB integrated and running on GlassFish application web server. Therefore the integration work of ActiveBPEL engine into GlassFish server was necessary. The testing scenarios element was tested.

3.3 *Assumptions for implementation*

The e-NVISION platform needs to interact with its human users. The basic communication protocol for consuming such "manual" or "human provided" services will reflect the following philosophy:

1. When a human interaction is required, a specialized "human integration service adapter" will be called. This integration service will dispatch to the user an email notifying him of the required action and it will include a web URL corresponding to the internal web form/application, thus providing means for the user to provide the required response or deliver the required information.
2. The web application will gather the information from the user and deliver it back to the platform which will resume its operation. In technical terms, the web form will consume the appropriate e-NVISION call-back service.

3.4 *Detailed description*

This description will provide the example of human interaction implementation in e-NVISION platform. It will explain the human interaction description in the previous sub-subsection with more details.

3.4.1 *General scenario*

This sub-sub-section is provided to shortly clarify the partial view of e-NVISION system usage, to explain human interaction usage possibilities.

It is intended to be a tool for e-Business support. To be a profitable this system must have as much registered users as possible. In general it is expected, that the core (the running business processes in BPEL and collaborative part in ebXML) of e-NVISION will be placed in main enterprise (General Contractor or Project Management Company – GC or PMC respectively). Other companies (partners or subcontractors) will be smaller companies with lesser or even minimum of possible e-NVISION components (simple ebMail sending applications or remote invocation possibility).

Most part of e-business communication flows will go from one partner trough GC (invoking implemented automated business process) to another partner and vice versa.

By executing automated business process (written in BPEL) there may appear the situation when the human interaction is required. For example, let us assume that some building and construction company (for instance, Build Ltd) is looking for suppliers of windows and doors. Build Ltd is registered to e-NVISION system and is a partner of a big company (the GC – Large Ltd). Latter enterprise gets an e-mail from Build Ltd with request for mentioned items. Such information initiates the business process in Large Ltd. Further the following search of required goods should be approved by GC. This task should be performed by human. After approve there will follow secondary steps of search in internal DB and externally where human interaction is also necessary, but for the sake of clarity only the first human interaction part (ask for approval) will be explained further.

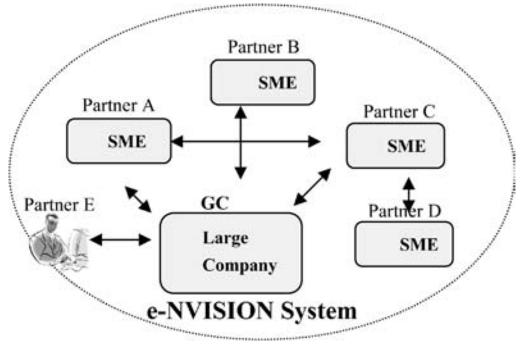

Figure 5. It describes the expected structure of e-NVISION system in building and construction sector. Almost all communication flows go through the GC.

3.4.2 *The invoke of human interaction*

Before the automated BPEL process flow reaches the place where the human interaction actions are expected some additional information should be passed too (Figure 6). Besides the data we would like to show for human actor (payload) BPEL process must also provide the callback address which will target the destination where to respond.

After all required data are assigned the "human integration service adapter" is called. The Bpel process runs asynchronously until the place where the response from the human is described and stops there in waiting for response stage. Meanwhile the invoked web service prepares all required data for human interaction:

- Generates the web page with its content (it could be trivial form with two buttons and specified question or it could be big form with a lot of dropdown lists and insert field).
- Place all data (and the page) in the DB and gets unique access address.
- The web service sends notification e-Mail for the human actor (in our case it could be a GC company's project manager) with request to approve (following the example). Besides the notification about the task that is needed the e-Mail contains mentioned unique access address (in form of URL) to the page. On this

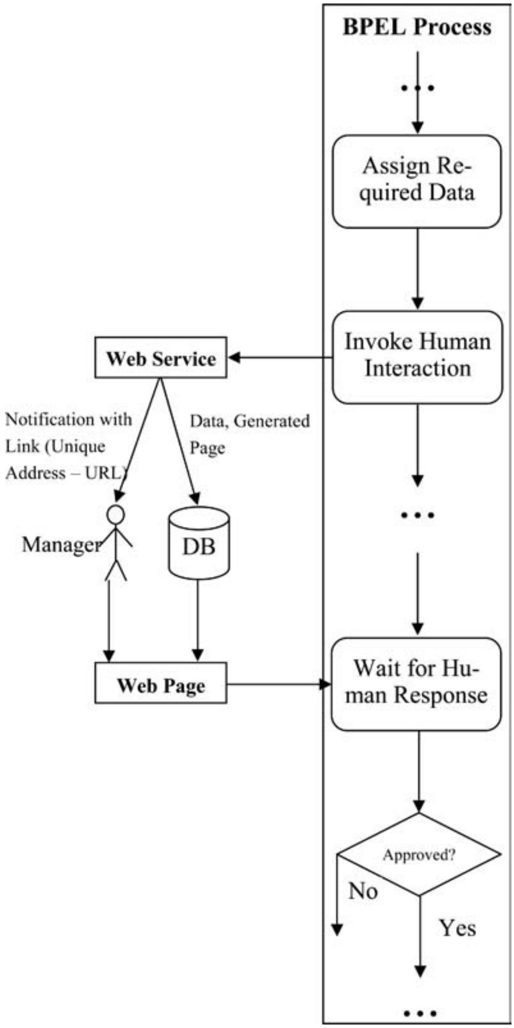

Figure 6. It provides the general structure of human interaction implementation in e-NVISION platform.

step this web service ("human integration service adapter") finishes its work.

3.4.3 *Human interaction response*

Once the responsible person (project manager of GC company) reads the notification (couple hours or even days could be passed after the e-Mail came) he clicks the link and the browser uploads the page with the question for approve the search for specified items (for example, windows and doors) requested by SME partner (for instance, earlier mentioned Build Ltd).

After the dedicated person submits his answer, the page responds back the results for the waiting BPEL process. At this moment human interaction task is finished.

Business process reads provided response data and performs needed actions further according to the response values.

4 CONCLUSION

The human interaction implementation which is used now is not based on the BPEL4People specification and do not uses people activity elements inside the BPEL process.

However the developed way to have human interaction possibilities is very similar to 4^{th} described opportunity with people activities where the human task is standalone and have web service interface for communication.

The main reasons for different implementations were:

– Lack of available BPEL4People implementation tools.
– Time limits to implement full BPEL4People functionality consuming big amount of our own financial and human recourses.

However, different way of human interaction implementation also had some problematic areas:

– Manual call back addresses creation. For this reason additional web service were needed, to provide call back address in automated way.
– Problems with doubled invoke of human interaction web services. The issue was in two identical response waiting endpoints in BPEL process since there was no way to identify which response belongs to which end point. To solve this issue some changes in web service interface file (WSDL) and additional testing were needed.

Summarizing the advantages of such implementation it is stated that provided solution was chosen because of:

– Simplicity to use. Only thing which is needed is to invoke web service.
– Exploitation of the web services. The main idea of e-NVISION platform operation is strongly based on the web services calls. Implementing human interaction functionality in such way would be most clear and appropriate solution.
– Universality of application. Human interaction implementation would be accessible from many local environments and its functionality would be not dependant on the specific implementation. Only thing is needed to know is the web service interface.
– The cost. Chosen implementation of human interaction was much cheaper then evaluated expenses in standard BPEL4People development.

Assuming that each non standard implementation is bad solution from the long term perspective provided solution will be switched to the standard implementation as soon as suitable for usage in e-NVISION project BPEL4People implementation appears.

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Author Index

Since 1994, the European Conference on Product and Process Modelling (www.ecppm.org) has been providing a review of research, development and industrial implementation of product and process model technology in construction. The task of structuring all the information on built environment has presented challenges to the research community, software developers and the industry for the last 20 years.

In this context, the 7th European Conference on Product and Process Modelling (ECPPM 2008) provided a unique discussion platform for topics of key importance for the AEC/FM industry, with a focus on two main themes:

- structuring of product and process information for enhanced collaborative teamwork and information sharing in this fragmented industry, and
- advanced Computing, Information and Communication Technology addressing the resolution of challenges for the AEC/FM industry in the upcoming years.

ECPPM 2008 was held on the 10-12 September 2008 and hosted by the French CSTB (Centre Scientifique et Technique du Bâtiment) in the Sophia Antipolis innovation park located in the French Riviera. The conference has continued the exploration of the leverage expected from modelling and ICT deployment in undertaking various AEC/FM processes. Hence, leading experts delivered up-to-date, comprehensive presentations on the broad achievements in research, development, standardisation and industrial implementation of product and process data technology. This book covers a large spectrum of topics, including process optimisation, extended products and future services for homes and buildings infrastructures, decision support systems for universal design of buildings, ICT-based applications for energy efficiency, environmental monitoring, the ageing population, assistive technologies for the built environment, policy, legal framework, and rules and regulations, and will be of interest to scientists and professionals working in these areas.

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