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Digital Architecture and Construction 2006

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Preface

In the early stages of its employment, architects approached computer technology as an assistance technique that would enhance architectural practice. The scope of this engagement was captured in the phrase ‘computer-aided architectural design.’ In the four decades since that time, the role of computer technology in architecture has gained a marked significance and led to a different approach to physical production/construction. The scope has now been extended for architects to contemplate ‘totally digital architecture design/construction.’

The main focus in the development of digital tools for enhancing the practice of architecture has been the facility with which the various tasks involved have been represented, enabled or enhanced using computer technology. The digital representation of architectural entities and the digital manipulation of those entities have provided alternate means to produce architecture (construction). Drawing, modeling, performance simulation, design collaboration, construction management and building fabrication are now routinely performed using computer-based technology. This success has revealed the untapped potential of the computational representation of architecture.

Developments in digital technology based on the study of natural processes such as neural processing, genetic evolution and emergence now suggest that the elusive nature of creative architectural thought can be articulated enough to be applied in a technologically-mediated environment. Digital tools may finally reveal what other architectural tools have hitherto concealed – the architectonics of architecture. Therein lays promise *(Ganapathy Mahalingam)*. The future of digital tools rests on the extent to which architects can accept that exemplary architectural designs that can be created in a computer-mediated environment and that digital thinking is indeed architectural thinking.

The digital age has radically reconfigured the relationship between conception and production, creating a direct digital link between what can be conceived and what can be built through “file-to-factory” processes of computer numerically controlled (CNC) fabrication *(Branko Kolarevic)*.

This newfound ability to generate construction information directly from design information is what defines the most profound aspect of contemporary architecture. The close relationship that once existed between architecture and construction (what was once the very nature of architectural practice) could potentially reemerge as an unintended but fortunate outcome of the new digital processes of production.

The digital generation of information to manufacture and construct buildings can render the present inefficient hierarchies of intermediation unnecessary.

The 1st International Conference on Digital Architecture & Construction considers these facts in the meeting. As architecture design and constructability becomes a direct function of computability, the question is, what new instruments of practice are needed to take advantage of the opportunities opened up by the digital modes of production?

The Editors,
Seoul, 2006

Contents

Which new semantic for new shapes?

B. Colajanni, G. Pellitteri & S. Concialdi
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Università di Palermo, Italy

Abstract

There are two innovations which have drastically changed the building process: the operational continuity of the design and construction phases, and the software allowing not only the representation but also the autonomous creation of complex shapes never before thought of just because they could not be represented. This last innovation gave rise to a new design paradigm whose tools, according to their supporters, are the most advanced fields of mathematics and information science. Some ways of using these new possibilities gave rise to a radical, problematic, change in the relationship net between the designer's intentions, the shapes through which they express them (invented or self-generated) and their semantic contents. The most radical position skips the problem denying the necessity of such a semantic content. A further question is raised when the context is thought to intervene directly in the shaping process of a building envelope.

Translating cultural influences into physical entities directly acting in transforming surfaces shapes entails a strongly idiosyncratic interpretation. Constructing a semantic code of shapes and context forces common to the sender (the architect that decides the shape) and the receiver of the communication (the social community in which the architecture is immersed) requires from the former a careful reflection on the meanings also beyond the sender's intentions, with which the community reads the designed shapes, according to its cultural standard.

The complexity of those processes has for a long time been the object of much debate. Some statements about the new paradigm seem to be metaphors rather than realities. Our contribution tries to detect some misunderstandings which a displaced use of some concepts has created have this nature. A design experiment is presented, that has been used as a test.
Keywords: digital architecture, topology, morphing, context forces.

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1 Introduction

There are two innovations which have deeply changed the building process: the operational continuity of the design and construction phases, and the software allowing not only the representation but also the autonomous creation of complex shapes never before thought of, just because they could not be represented. The former is by now a widespread, almost universal, part of any building processes. The latter has experienced a different reception. Some architects smoothly introduced the new software into their design habits, drawing out of it all the instrumental capabilities offered. Some others, conjugating these possibilities with their eager interest for contemporary science and philosophy, have claimed the birth of a new architectural paradigm or, better, “the” new architecture paradigm, the only one allowing, at present, to “think architecture” an expression of Gilles Deleuze the present philosophical compass of the new architects. The well-known assertion of Gregg Lynn: “*The nineties started angular and ended curvilinear. In Architecture started Decostructivist and ended topological*” [1] summarizes this position well. Such a “fundamentalist” paradigm would deny architects like Renzo Piano or Tadao Ando the right of representing a valid alternative approach to design. Of course this claim of exclusivity can hardly be shared. However some arguments supporting the claim have deep theoretical implications, and deserve consideration. Others are mere metaphors, and are to be interpreted as such. Although widely discussed, a short summary of these metaphors can be useful in order to get rid of the misunderstanding they convey. This is done in Section 2. In Section 3 the main tool of the new paradigm “deformation” is examined. Section 4 signals the crucial problem of meaning. Section 5 refers to an experiment aimed at verifying some theses concerning the relationship shape-context forces.

2 Magic words and metaphors

Mathematics, and mainly Geometry has had, throughout history, constant relationships with architecture. Fruitful relationships, as long as its theories were directly translated into real, physical applications. The present interest seems to have a somewhat different character. Abstract, conventional mathematical concepts, are attributed as properties to architectural spaces or design procedures; and the fitness of the attribution is often questionable.

The enthusiasm for mathematics and philosophy is such as to graze infatuation. Mathematics is the kernel of the actual graphic software. The current use of this software has perhaps been felt by some architects as a frequentation of advanced mathematics. From this feeling the architects may have derived the sensation of having entered, as protagonists, a cultural environment of which mathematics is the core (together with philosophy). The relationship looks more metaphorical than real. Metaphors are free from the obligation of a deep understanding of the concepts, as well as of their real application. They allow an easy appropriation of the “aura” of up-to-date science and the following positive connotation; that is just what the architects pretend.

A dictionary of the seminal words of the new architecture is certainly comprised of the following terms: non-Euclidean geometry, topology, dynamics, morphing unpredictability. Their use, as formerly said, is not exactly corresponding to their current meaning. A short analysis of a few of them is carried out in order to better grasp the key for understanding this kind of dictionary.

Non-Euclidean Geometry is an expression to which more than one meaning is attached. An easy remark could be that the geometry of a sphere is elliptical, hence, non Euclidean. It would be daring to infer that any spherical vault is a piece of "new architecture". The same can be said of all the analytical surfaces, such as quadrics, torus, and so on. On any surface, except on the plan, the possible geometry is non Euclidean. The "new architects" privilege a typology of surfaces (the NURBS) on which the non-validity of the Euclidean Geometry is pure triviality. Analogue misuse seems to be made of the word Cartesian: the formal aspect of orthogonal-based architectures is taken as consequences of the orthogonality of the Cartesian coordinated axes. The combination of the anathema to Euclidean geometry and to Cartesian space generates the following "disequation": [Euclidean Architecture + Cartesian Reference System] → modernist, rectilinear-orthogonal architecture → old architecture → unable to represent contemporary culture << [non-Euclidean, curvilinear, topological, morpho-generated Architecture] → representative of the contemporary cultures → in touch with the actual science and philosophy.

Another interpretation of non-Euclidean geometry describes it as a four-dimensional (or greater) geometry. Again, it is easy to observe that Computer Graphics allows one to draw only two-dimensional projections of geometrical four-dimensional (or greater) geometric entities which will always remain nothing more than projections on a two-dimensional space. Three-dimensional projections, when possible, as, for instance, is the case of the hypercube, are but assemblages of 3D volumes. Why then to refer to four-dimensional spaces that cannot become real architecture?

Sometimes, time is the fourth dimension referred to. Again, an unclear interpretation may be a synonym of dynamics or else the concept chain: time → change → dynamics → topology→ morphing → new architecture. However, this is not a novelty. Both Guillaume Apollinaire and Marcel Duchamp since 1912–1913 mention the fourth dimension of the non-Euclidean Geometry as the matrix of their space [2]. The same was done by the Italian futurists.

Regard *Topology* a simple definition describes it as "*the mathematical study of the properties that are preserved through deformations, twisting and stretching of objects. Tearing however is not allowed*" [3]. Deformation is the key word which leads to the architectural use of topology. From topological point of view a sphere, a cube as well as all convex polyhedra are topologically equivalent since all of them have 2 as Euler characteristic value. No "new architect" would consider these surfaces as architectonically equivalent or, worse, equivalent to a deformed surface of an envelope designed by him. What "topological architects" care for is software that is able to deform shapes. The aim is to obtain surfaces not otherwise obtainable or thinkable if not already seen after the unpredictable generation and representation. The task is the deformed surface, the final result, not the procedure. At the end of the process, whatever is the generating procedure there is a NURBS surface, unavoidably existing in the scorned Euclidean space and described by means of the Cartesian coordinates of the control points. In the new architecture jargon, the emphasis is on the concept of transformation. In other words, the shapes must not be common, simple, or recognizable. They must be transformed, deformed, and unequivocally recognized as such. It is like transformation and deformation guarantee the necessary transgression of the "dull" order attributed to "Euclidean geometry" Counter-check. Gehry's surfaces are created with somewhat handicraft methods, not *deforming* but directly *forming* the architectural models. They may look, to eyes wanting to see that, as deformed, but they are not. Forms are similar, the creation process is not. Then, if the positive connotation derives from the process of deformation, it cannot be attributed to these forms. However, they are absolutely akin to the ones obtained by deformation. Conclusive is the witness of Jim Glimph of Gehry's studio on the first design of the Los Angeles Walt Disney Auditorium: "*Study models were generated very quickly, spontaneously, around the basic ideas of the project. The development of sail-like forms and that kind of imagery was all done in physical model. There was no computer modeling at all. In fact, at that time, there were no computers in the office*" [4]. Hence the nature of those forms did not depend on the use of computers. And hence again, the assertion that these forms are topological is that they have a non-Euclidean geometrical-topological ontology is not at all demonstrated. Just the contrary of what, M. Emmer asserts, i.e. that Gehry's Guggenheim Museum in Manhattan is "*an even more topological project than that of the new Guggenheim museum in Bilbao*" [5]. William Mitchell views Gehry's iterative multimedia process as "*far more revolutionary*" [6]. The thesis is contested by Lenoir and Alt: "*he is in fact doing nothing revolutionary*" [7].

Morphing is but the set of procedure of obtaining deformed shapes.

A summary of the theoretical bases of "new architecture" may be found in the following Kolarevic' sentence [8]: "*The defining element of the topological architecture is its departure from the Euclidean geometry of discrete volumes represented in Cartesian space, and the extensive use of topological (rubber – sheet geometry) of continuous curves and surfaces, mathematically described as NURBS*".

3 Deformation as a design criterion

There are two different ways of deforming shape. The grounding character of the first is the control of the start and the end shape of the process. Moreover, there are yet two variants of the procedure. One of them is the classical morphing. You start from a known shape, you choose an arrival shape, and the procedure builds as many intermediate shapes as you want. In some way you can foresee the type of shapes you will get. The result depends on the difference between starting and final shape. If the latter is a transformation of the former, the purpose is choosing the fittest hue in a field of substantially homogeneous solutions. If starting and final shapes are thoroughly different the aim is a true exploration of possibly unexpected results that highly divergent formal concepts may generate out of their reciprocal reaction.

The second way also has two variants. The starting point is for both a tentative shape. One variant commits the deformation to purely conventional, geometrical procedural rules; the second commits the deformation to a system of forces directly acting on the shape. The simulation is carried on a model endowed with virtual, global mechanical properties. Virtual mechanical forces (also possible metaphors of non-physical influences) are expected to produce virtual mechanical deformations. The aim is ambitious, the simulation of the effect that the context exerts on the shape. Some perplexities raise naturally. Let us refer to Franken's words: "*Admittedly, we cannot grasp forces directly with our senses, but can only infer them through their effects. Our experience, however made is very sensitive to deformations that correspond to a natural play of forces. Our perception is thus conditioned toward forces, and uses them to interpret shapes. Deformed forms carry information about the forces at their origin*" [8]. Substantially, Franken affirms the "a priori" impossibility of grasping the system of context forces before their action on the objects. From their effects they can only be inferred, not known. Moreover, information about the origin of the forces can be drawn only interpreting the deformation with our sensibility. So, if the hearth of the design procedure is the deformation effect of such a force system it is difficult to avoid the rise of some perplexities. How to foresee the system of forces to which the designed shape has to be submitted, if also its origin can be inferred only from occurred deformation? And, overall, how to translate non-physical forces into mechanical (physical) models of action and reaction? Isn't the determination of the force systems, supposedly representing the influence of the context, somewhat hydiosincratic, largely subjective, and, eventually, arbitrary inasmuch as it is not susceptible of popperian validation? And how to decide the degree of virtual deformability of the shape? Also an interactive procedure generating a series of refined solution cannot escape the arbitrariness of guessing the system of context forces. Notwithstanding all those uncertainties Franken has no doubts: "*The forms we generate are never arbitrary, they can be explained and are subject to rationalisation*" [9]. We maintain our perplexities on the real correspondence of the obtained results to the asserted procedure independently of their architectural value, which is, in the end, the only thing that has importance.

4 The meaning

Another question is the meaning these architectures can express. A very complex question, that of course we have neither intention nor claim to discuss. Nonetheless, we will express some remarks.

The question of meaning is linked with more than one concept of the new architects' theorisations: unpredictability, the intentional seek of indeterminacy, direct action of environment forces in the design process. A form, however generated, is perceived. Perception involves vision. Which is, using the words of

Eisenman: "*linking seeing to thinking, the eye to the mind*" [10]. A malicious reader could recognize in this assertion an echo of the wölflinian purovisibilism [11]; from Kolarevic's "*Back to the future*" to an Eisenman's "*Forward to the past*"? In the same text he proposes to "*detach what one sees from what one knows, the eye from the mind*". It seems really doubtful to consider this proposed first step as possible. The purpose of this detachment is to skip the difficulties that the vision of a unpredicted and hence at least partially uncontrolled shape may meet "*When the environment is inscribed or folded in such a way, the individual no longer remains the discursive function, the individual is no longer required to understand or interpret space*" [10]. "*What one knows*" is the mental set of knowledge to which the perception autonomously refers in order to understand what has been perceived. Is a mechanism that cannot be voluntarily blocked whether or not "*the individual is required to understand and interpret*"; the individual will however try to do it. Moreover, Eisenman himself acknowledges the imperious demand of the eye and the body to orient itself in architectural space through process of rational "perspectival" ordering. Assertion to share but one point. The word perspectival is superfluous and misleading. In fact, the critics to non-curvilinear, non-folding, and non-topological, non architecture is based on the statement that, until now, the architectural vision has been perspectival. What is not. So the question is displaced. The processes of form generation can be meta-controlled, that is they can be given rules and restraints. Is it enough to guarantee that the process will generate forms susceptible of an interpretation giving meaning to them? A form can be given a sense, a meaning, a value also "a posteriori", as it were a natural object, not an artefact. But this reduces, not enhances the range of its communication capabilities. Two ways are opened to the architect: either they are able to control the output of the form generation – and in this case the form must be, in some way, predictable – or they are not, and in this case they have to accept the randomness of the results [12]. However, this is the new paradigm of design. It changes and, eventually, reduces the responsibility and role of architect in shaping the communication capabilities of his work.

This shaping principle clashes with the opposed one: shapes configured by context forces.

5 An experiment

The theory of the influence that contest forces exert on the formal choices of architects sensitive to them seems in the same time, convincing and dubious. Convincing because of its reference to environmental aspect of which an objective presence is asserted. Dubious because this objectivity is subjectively asserted; which seems a patent contradiction.

It seems reasonable to think that much depends on the "strength" of the context, of the presence of highly characterized natural configurations or dynamic phenomena. We decided to perform a simple experiment: the simulation of the deforming activity of "landscape forces" on a project previously designed. The environment is a place at the foot of the mountain chain closing the Palermo plain. The mountain behind the lot is the dominant element of the close environment. The hypothesis is that the mountain exerts an attractive force tending to distort "autonomous" volumes, geometrically defined according to only self-referenced configurations. The attraction should fold the volumes towards the mountain. The project chosen as the basis of the transformation experiment was designed in a composition course. It fits well to the experiment, as its shape is geometrically clear, self-centered, and independent from context influences. The project comprises a small airport station with an annexed flight school, a congress center, and a hotel. For simplicity sake the building was simplifies discarding the station and the school. The meeting halls of the congress center acquired the characters of auditoriums. The software tool was 3DS Max©. Catia© was used for some intermediate steps, not reported for brevity sake.

A first phase is a morphing process not immediately bound with the action of forces. The start schema models only the dimensional and relational properties of the single functional spaces. Each of them is represented as a parallelepiped having surface and height as foreseen in the project. The end model is the original project from which some secondary elements have been withdrawn. The procedure is, in a sense, a control of the logic of the original project. In fact it relates the chosen (final) solution with the pure functional requirements of the schema.

Figure 1: Steps of the morphing procedure. Left: start shape with functional parallelepipeds. Center: intermediate configuration created by the morphing software. Right: final ideal shape from the original project.

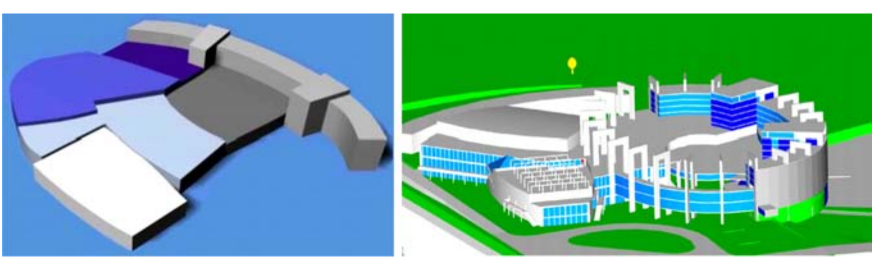

Figure 2: Final shape drawn from the intermediate morphed configuration; and the original project.

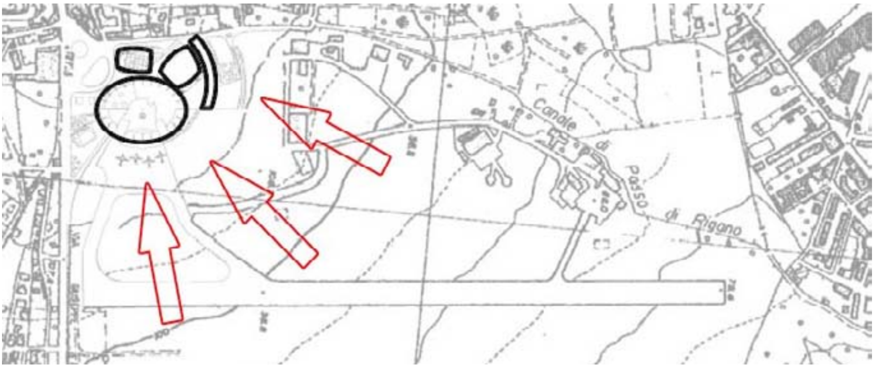

Figure 3: Plan showing the context forces.

The fiftieth configuration out of the hundred generated by the morphing was chosen as a good compromise between pure functional requirement and mainly formal criterion. Small adjustments were hand made.

The following phase brings the context forces. The volume most sensible to the attraction of the dominant mountain is the hotel because of its height and slimness. The most important point of view is the access street. The searched effect has to be well visible from it. The attraction of the mountain was interpreted as a set of forces directed towards it and applied as a thrust to the side of the hotel body opposite to the mountain. This has already been modified (taper) in submission to the context restraints imposed by the airport nearing plans. Besides the contest forces, the sensitivity of the hotel body to them had to be evaluated and simulated. A possible way was to compute the deformations of the hotel body by means of Finite Elements (FE) software, recycling and modifying intensity of forces and/or elasticity of the structure until a visible deformation could be obtained. This way besides being long had an intrinsic contradiction. Elastic deformations are always small enough as not to change the geometric conditions of the static equilibrium; just the contrary of what is needed. 3DS Max© supplies another way: the volume is considered as made of a soft material, whose behavior is conditioned by some parameters as mass, friction, relative density, stiffness damping, air resistance. The acting force is wind. This mechanism of simulation allows much more intense deformations, more deep and irregularly than a FE software could do. In the simulation, some elements are restrained to the soil, representing a certain resistance to the context force, besides the necessary stability. Figure 4 shows the results on both sides of the hotel body.

The results of the experiment are not immediately readable. An analysis of the results does not dissolve the perplexities. The deformations are wide and somewhat irregular. The relationship with the mountain lying behind can be understood only after a careful consideration of some data of the procedure. The shape of the inward flexion of the lee side is a consequence of the restraining effect of the two towers and of the upper chain. On the mountain side an extroflexion can be read as the effect of an attraction, again restrained by the fixed elements of the building.

Many other aspects of the experiment, as the procedure of communication between 3DS Max© and Catia© or the use of the FE software present in the latter are not reported because not pertaining to the topic of this paper.

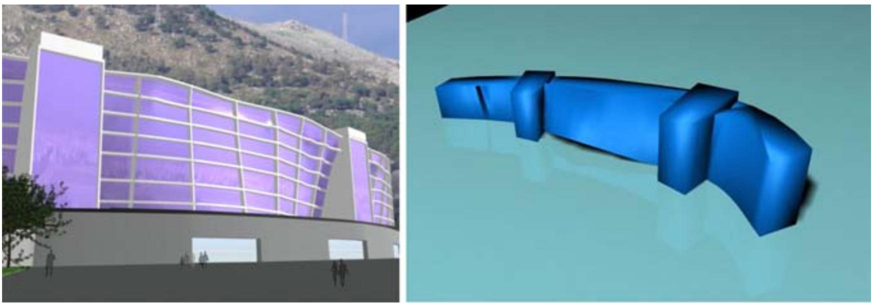

Figure 4: South façade after morphing and north façade after morphing.

6 Conclusions

Of course the experiment is very simple and does not pretend to give enough elements to dissipate all the perplexities that arise in such an innovative approach. The morphing procedure is powerful. It allows the reshaping of previous forms as much as desired. Less easy is mastering the results once the object parameters, the restraints, and the force fields are given. We think that the subjectivity of the interpretation of the force fields is substantially confirmed. We do not think that the looseness of correspondence between the hypothesized nature of the context forces and the voluntary model in which they are translated denies reliability to the procedure. It only brings the same looseness in the meaning that the deformed shapes are able to express. However, this is nothing new: subjectivity, i.e. personal individual characterization, has always been the very essence of art and then of architecture. What is wrong is denying this subjectivity.

Something like can be said about the two main assertions of the so called "New Architecture". On one side the pretension that their approach to correspond, interpret, and embody the results of the most advanced science and philosophy [13]. On the other, that only their approach can guarantee such correspondence, interpretation, embodiment. The first statement may hide a substantial weakness and uncertainty, disguised in certitudes, seeking in other disciplines the legitimacy they do not find in their own. We hardly touched on some questionable ways of interpreting mathematical concepts, such as topology or non-Euclidean geometry. Mental schemes having similar abstract conceptual structure can indeed exist in different disciplines [14]. Sometimes, however, the similarity is only apparent, or regards only secondary aspects. What seems hardly convincing is the pretension to appropriate the "aura" of extreme advancement, scientificity, and depth of knowledge, from sometimes only superficial similarities or quite misunderstandings.

With regards to the second pretension, it is enough to leaf through the magazines of architecture to perceive that a lot of beautiful Euclidean, rectilinear buildings are built the world over.

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Fluid (in)form and the encoding of space

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Abstract

The architect is faced with a multifaceted design problem when designing the roof, particularly where rain is concerned. The roof must be load bearing, supporting not only its own weight, but also that of any collecting water or snow. In an area with a severe rainy season such as Florida, this problem is magnified exponentially. This project addresses the nature of water as it interacts with a roof form by testing various roof designs and pitches, and helps educate the design students to the essential needs in the design of a roof system. Through the benefit of experience, an architect or educator can use intuition and experience to be able to point to a roof portion and say that water will collect here inappropriately. However, it is something completely different for the architect or student to be able to test their theory and see water actually collect on their architectural model and infiltrate their design through the use of computer animation. This paper outlines the experiment with rain simulation, presents the outcomes, and critiques the interdisciplinary relationship between disparate bodies of researchers and students involved.
Keywords: digital modelling, computer simulation, design education, particle systems.

1 Premise

"My earliest childhood memories are related to a ranch my family owned near the village of Mazamitla. It was a pueblo with hills, formed by houses with tile roofs and immense eaves to shield passers-by from the heavy rains which fall in that area. Even the earth's colour was interesting because it was red earth. In this village, the water distribution system consisted of great gutted logs, in the form of troughs, which ran on a support structure of tree forks, five meters high, above the roofs. The aqueduct crossed over the town, reaching the patios, where there were great stone fountains to receive the water. The patios outside the

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stables, with cows and chickens, all together. Outside, in the street, there were iron rings to tie the horses. The channeled logs, covered with moss, dripped water all over town, of course. It gave this village the ambience of a fairy tale" [1].

The early work of Christopher Alexander and Nicholas Negroponte marked the beginning of architects' selective flirtation with computational technologies. In recent years work developed in the context of Columbia's Paperless Studio and its spin-offs has embraced the fluid form-making potential of programs such as Maya in an effort to subvert the strictures of Cartesian space. This group has also challenged the authorial will of the individual architect by assigning spatial and temporal properties to abstract concepts and setting these now-spatialized concepts in motion. The resulting interaction produces a collision of amorphous forms, currently described colloquially as "blobs."

Our project takes the same issues – the quest for an appropriate fit between computational promise and form-making and a fascination with shaping complex flows – in a different direction. We pose this architectural question: How does architecture shape and redirect one of the earth's physical "flows" – water – as it falls in the form of rain? Can we model rainfall digitally, and then shape surfaces such as roofs, terraces or landscapes to design the flow of water? Can this flow be conceived as a design opportunity, contributing to the phenomenal experience of a project as it is simultaneously shed more responsibly to the larger landscape? Can the poetic exploration of fluids prevalent within the academy be transformed into equally poetic tangible applications?

These are some of the questions we set out to explore, working in collaboration with colleagues in the University of Florida Global Information Systems Center and Digital Worlds Institute (DW). Fifteen students and three faculty members culled from our senior architecture studio met over a period of several weeks with faculty and graduate students with expertise in urban planning, engineering and fine arts. First our architecture students were required to develop a rudimentary understand of GIS regional mapping capacity, with a particular emphasis on the study of hydrology and watersheds across our watery state of Florida. Following this regional analysis we developed a method to demonstrate the water shed by individual student's projects set within this larger landscape. Students first translated their physical models of modest (1000 sf) projects into three-dimensional digital models, then into animations to which rain could be "applied." Students' representations moved from chalk pastel to GIS to basswood to AutoCAD to 3D Studio Max and finally to Maya. Difficulties in translation and changes in material behaviors occurred at each state, and form the primary focus of this paper.

1.1 Precedents

Since Renaissance theorists Alberti and Brunelleschi developed a systematic process to construct three-dimensional perspectives on a two-dimensional plane, architects and theorists have forayed into various emergent technologies of spatial representation. Rene Descartes used algebra to develop a coordinate system that removed the necessity of tools or even reference to the real world.

Nearly four hundred years later, during the 1980s, a new type of spatial research and system emerged in the guise of virtual reality. Early attempts to create a multi-sensual virtual world required a pair of goggles, headphones, and a glove so that one could see, hear, and feel objects modelled in a computer environment. These interfaces were quite cumbersome, and of course inconvenient if one were to imagine working with such a situation on a daily basis. However, they did set the foundation for countless later attempts at designing an artificial world, a cyberspace as described by William Gibson in Neuromancer:

"...cyberspace has a spatial and architectural form that is dematerialized, dynamic and devoid of the laws of physics; spaces in which the mind can explore free of the body; spaces that are in every way socially constructed, produced and abstract. As such, the architecture of cyberspace only mirrors that of Cartesian logic if that is how we straitjacket it" [2].

Arguably, a digital aesthetic has emerged in the architectural world. Those who have begun to explore the notion of an indigenous digital architectural language have come to utilize similar design elements, forms, and spaces in their work. Offices such as the UNstudio, Asymptote, Greg Lynn Form, Architectonics, and Diller-Scofidio who strive to find the architecture of cyberspace instead of simulating the architecture of the physical world have published widely their flowing, transparent, layered projects that seem quite as home in a molecular biology experiment as in a design studio context. Entranced by the idea of interconnectivity, speed, efficiency, and spatial dynamics, these designers began to explore forms only possible through the use of computer modelling technology. New formal typologies continue to emerge that challenges our understanding of the built and designed environment. As these projects begin to be built, often requiring new technologies of construction and fabrication, we start to understand the physical inhabitation of such dynamic environments as being quite different than those of the parallel and angular.

Since the early 1990s, dynamic digital forms have proliferated in graduate schools across the world, thanks largely to the efforts of young faculty members at schools such as Columbia University, Princeton, Cooper Union, UCLA, and Sci-Arc. What is important to note is that by the early nineties, graduates and recent graduates architects were the first generation to not have been educated by the giants of modernism, such as Le Corbusier, Kahn, Aalto, and Mies. The tenets of modernism were distilled through an older generation of faculty, who themselves were exploring ways to expand upon the dogma of their teachers. Hungry for a new language of design, a new way to understand urban form and space, this new generation looked to the digital revolution for inspiration.

"Liquid architecture is an architecture that breathes, pulses, leaps as one form and lands as another. Liquid architecture is an architecture whose form is contingent on the interests of the beholder; it is an architecture that opens to welcome me and closes to defend me; it is an architecture without doors and hallways, where the next room is always where I need it to be and what I need it to be" [3].

Perhaps the most noted innovator of digital architecture is Greg Lynn. Lynn began adapting software to the design of complex conceptual models in the late 1980s while at Eisenman Architects, and has continued to evolve his practice and research along with the digital explosion of the 1990s. What Lynn professes to do is typical of his generation – mapping contextual and programmatic forces of a project then modelling them in a way that allows the architecture to grow directly from the data. In this sense, the will of the architect is removed from the equation, and the design is autogenerative. For instance, he uses software such as Maya to create particle flows that simulate pedestrian and vehicular traffic in his entry for the Port Authority Gateway Competition. Particles are dispersed along routes of traffic responding to gravity and one another to create a "phase portrait" [4]. Architectural form is then essentially derived directly from the vectors describing the motion of the particles. Many of the current generation of architects using this technology to create their formal language operate in this manner, allowing the software to create the architecture rather than simply to inform it.

One of the biggest problems with this type of design pedagogy is that it is predicated on the tool. Specifically, design possibilities are limited to a certain degree by the type of software used and the capabilities that the software has in relation to creating architectural form. Thanks to software packages such as Maya and Form Z, a new architectural language has emerged that challenges both the tenets of the discourse of architecture and standard construction means and methods. Not unexpectedly, projects built using this method tend to suffer from the abrupt translation from a digital to the physical realm.

While retaining a fascination with the fluid, we have applied the same digital parameters to understanding the dynamics of environmental forces that affect the built environment. Instead of modelling fluid forms that depict the circulation patterns of a site as Lynn does, we chose to simulate the fluid nature of water as it interacts with a building, so that the design may be improved accordingly. Ultimately we would hope to shape our chosen fluid, water, indirectly, by strategically shaping architectural form.

2 Process

One of the many paradoxes that digital tools present is the seemingly infinite operations that are achievable with such little effort. Though simple in premise, the task of digitally simulating rainfall in an accurate and measured way has proven to be remarkable challenging. Given the plethora of software that are available and their intrinsic complexities, it became immediately apparent that we would need to look far a partner with greater familiarity and programming expertise. For these reasons we forged a connection between our School and one of the University of Florida's premier interdisciplinary centers, the Digital Worlds Institute currently housed jointly in the colleges of Engineering and Fine Arts.

Realizing the institutional friction a formal collaboration might create, we began simply. Three architecture professors set aside a two-week segment within a design studio dedicated to building in the Florida landscape. Our climate (semi-tropical with daily rainfall all summer) makes a study of water obvious and, in retrospect, almost essential. We posed this question to the students and faculty in an ongoing special topics research seminar taught within the Digital Worlds Institute: Can the flow of rainfall onto a building and landscape be digitally simulated in such a way that students can understand the repercussions of their designs and then work to modify their structures to more responsibly and poetically shed water?

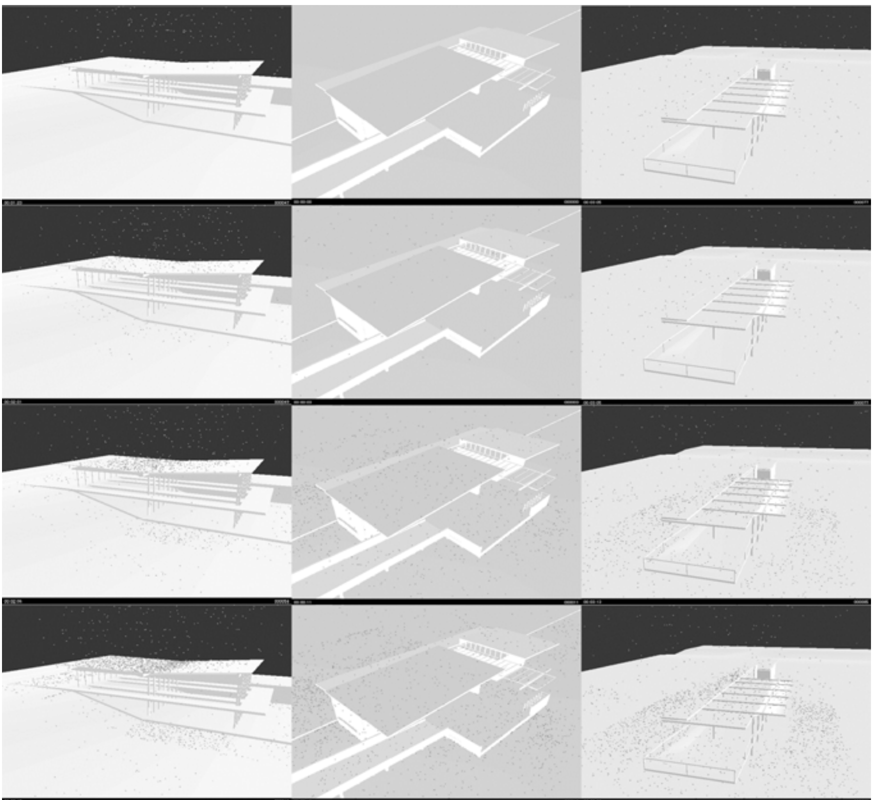

Figure 1: Captured stills from Maya.

After a series of discussions regarding software alternatives, Maya was selected as the testing platform, given its capacities to simulate gravitational behavior and impeding surfaces. With the assistance of the Digital Worlds Institute, the students were able to successfully import their virtual models into the dynamic animation environment found within Maya. Exported as .dxf files from 3D Studio Max and introduced to the Maya three-dimensional environment, the process for particle simulation was relatively simple. Maya allowed for the creation of a particle emitting source element placed above the model and a gravity element created below the model to control the direction of particle movement. This system established the preliminary condition of purely vertical particulate flow as an abstraction of individual raindrops falling. Density was modulated through a numerical system of randomly located particles emitted with an upward limit of 500 particles/second. Adjustments with particle size accounted for the approximate size of individual drops. Modulation of the particle's dynamic response to encountered surfaces allowed for an approximation of splash. Further definition within the model itself was required in order for the particles to react to the model surfaces directly. All modelled surfaces required definition as either an active (impenetrable) or inactive (penetrable) surface. An inactive surface would have no impact on the direction or rate of travel of the particles, particles simply passed through them. Active surfaces could alter both the direction and rate of descent of particles, determined by the orientation of the surface itself as well as adjustments within the friction characteristics assigned to that surface.

The product of this simulation was a short length digital animation displaying the idealized behavior of raindrops falling onto an architectural construct and landscape. Though numerically indeterminate, the animations did allow for a visual means of analysis regarding roof and site drainage within the specific limitations of this scenario. The animations clearly delineated the fundamental principles of fluid movement across varied planes that provided visual confirmation of general drainage patterns and collection points within the tectonic elements of the architecture as well as the diagrammatic conditions of site.

The process of development for this simulation prototype also revealed numerous difficulties specific to digital media, stemming primarily from software interaction. The most dominant struggle occurred with the interface between Maya and 3D Studio Max. The necessity of a plug-in for importing Max files was not initially known. Only after several days of struggle on the part of the DW was the software interface problem solved, and even then only with the addition of a secondary software element. Equally, the software interface appeared to only work with .dxf files written directly from Max. Though this was much less of a problem due to the relative ease of translation between the various modelling programs used by students, it still imposed an additional level of file translation as well as the possibility for file corruption or data loss.

Once the files were in Maya, a new set of challenges became apparent, ranging from software and hardware limitations to lack of familiarity by the user. Though the DW had been successful in projecting particles onto a surface and incurring an effective representation of gravitational flow, the behavior of the particles could not be adapted to fit the characteristics of fluid movement. The resulting simulations, though indicative of general flow patterns were more fictional at roof edges, where the particles followed a trajectory which was in fact noticeably longer in horizontal throw than would actually occur with liquid flow. Equally, the particles necessarily remained autonomous as elements, not interacting or combining with adjacent particles to form larger fluid bodies, which in turn allowed for only the suggestion of pooling water on a roof or a site. They never exhibited cohesion. While Maya 4.5 does have potential for the animation of fluid behavior, the lack of familiarity with the program effectively

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limited the simulation to a system of particle animation. Neither the students nor DW had enough working versatility within Maya to fully take advantage of the program's potential, let alone the possibility of innovative usage to achieve a specific type of effect.

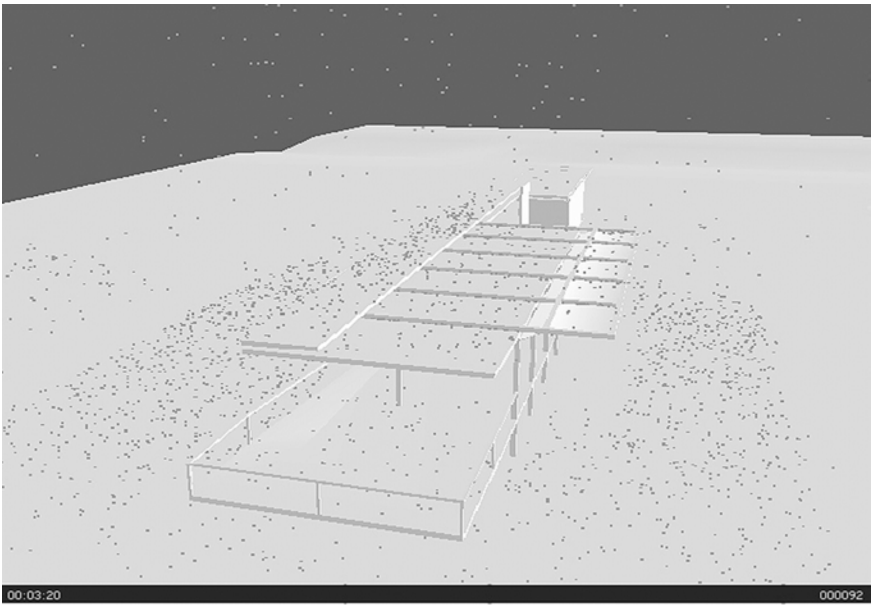

Figure 2: Designed project inserted into the particle simulation environment.

As Maya is primarily intended as animation effect software, the computational limitations became equally apparent. Though density of rainfall could be visually adjusted, rainfall intensity was effectively limited by the size and number of emitting elements. The choice to use multiple emitting elements would have increased the file size and complexity, and applied further strain to the processing capacity of the system. At the very least it would have substantially increased animation times, if it did not crash the entire system.

The particle emission rate was qualitatively inconvertible. Any specific calibration to a more common system of notation, such as inches per hour, could not be achieved. In addition, environmental factors such as constant or gusting winds could not be explored in the allotted time. The possibility of surface distinction was equally vague. Permeability of surfaces could be implied with adjusted friction, but the particles could not penetrate the surface, only move more slowly on it.

A further compounding struggle was the hardware itself. Maya's intensive operations require a powerful CPU in both processor speed and memory. Model complexity and thus accuracy had to be kept to a minimum in order to simplify the particle simulation. In addition, once the models were imported into Maya 4.5, all operations had to be performed with this version. Preceding versions of Maya were not compatible, resulting in a reduction of the available number of viable software seats.

Later experimentations involved Max exclusively instead of Maya due to the improved inter-changeability of file formats between programs. At the time, this hindrance proved quite time consuming and limited the ultimate outcome. Max directly imports the students' AutoCAD model files, and allows for a more logical assignment of material characteristics than Maya. Solid objects are assigned to be Rigid Bodies so that the particle system simulating rain cannot pass through them. Max also allowed for more control over the simulated rain. The amount, direction, intensity, size, and speed of rain drips are controllable through extensive parametric settings. These options are easily adjusted for different climatic situations, so one can test rain run off for simple rain showers as well as hurricanes and snowstorms if the need arises.

One of the new challenges with the research is to make the rain particles also act with fluid characteristics when they pool together. Though not essential to the project, the inability to transform the particles to fluids became somewhat of an elusive aspiration. Even with the lifespan for the particles set to a maximum value, once the particle ceased to move and collected together they resembled a somewhat gooey mass of ping-pong balls.

3 Conclusions

The collaboration recounted here highlighted the challenges of interdisciplinary exchange and the importance of intangible personal qualities and methods for problem solving. This experiment brought to light not only the strengths and limitations of the each of the disciplines involved, but also exposed the representational preferences of each. Given the architecture students' strengths with visualization, the modelling software interface proved highly effective, allowing for basic modulations and adjustments with intuitive operations within a three-dimensional environment. However, when the questions arose regarding file formatting, or specific value characteristics of a tool or operation, the architecture students quickly became frustrated. As a counterpoint to this method of thinking, the DW participants excelled with the intricacies and nuances of the software, departing from more intuitive methods of working in favour of a stronger methodology and numerical understanding of each operation.

We were gratified to see an emerging collaborative ethos among our students. Although the project initially privileged the knowledge base and technology housed within the Digital Worlds Institute, the architecture students' diligence, enthusiasm and expertise turned our team from the DW's "clients" into true collaborators. By the end of the two-week experiment our students were answering as many questions as they asked.

While this modest collaboration between distinct disciplines provided some preliminary cohesion – temporarily turning particulate disciplinary studies into a fluid exchange – our primary goal remains untested. Our objective is to use dynamic particle simulation to influence design decision-making. To date we have crudely modelled a fluid condition, but we have not yet helped our students use the properties of rain, our chosen fluid, to inform design.

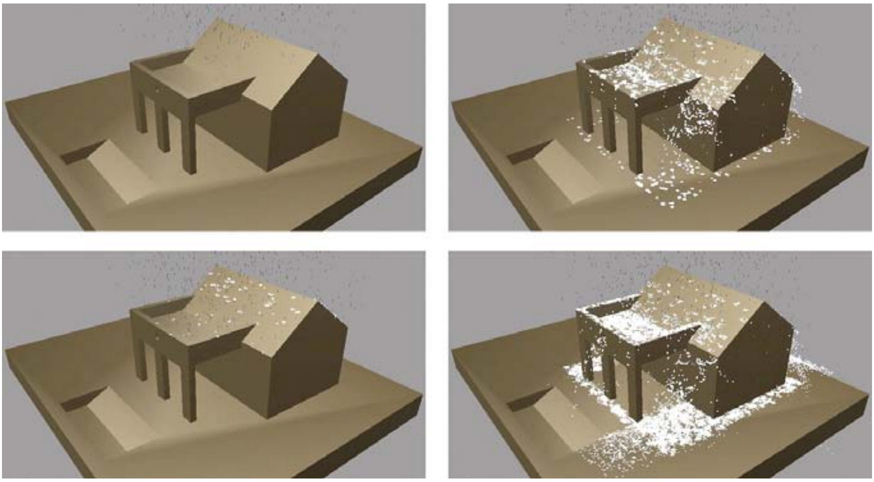

Figure 3: Further attempt of modelling rain with instanced blobby surfaces.

Finally, this project has been developed between individual faculty members outside of broader institutional support. In the long run, such collaborations can only be fully realized if they are offered stronger support from within each discipline, more fluidly integrating new proposals and investigations with existing intradisciplinary programs rather than the perpetuation of a more proprietary attitude. The potential of a truly collegial relationship between otherwise disparate disciples could help to offset the constrained fiscal environment most departments, schools, and universities operate within.

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SpaceCustomiser: InterActive

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Abstract

SpaceCustomiser is an ongoing research focusing on the development of digital methodologies and tools for designs based on non-Euclidean geometries. This paper describes SpaceCustomiser: InterActive, which deals with the development of digital design strategies based on non-Euclidean geometries, whereas the body in movement generates interactively architectural SPACE. The input – movement – is being electronically processed in such a way that the output represents a continuous, real-time modification of the space. For this purpose an on-site-built InterFace employing sensor/actuator technology enables translation of the recorded movement into spatial configurations. The InterAction between the body and the architectural space gives insight into how the human body shapes space.
Keywords: interactive prototype, interactive architecture, graphical programming, movement tracking, non-Euclidean geometries.

1 Content

The interactive processes in the SpaceCustomiser: InterActive project are controlled with software developed by K. de Bodt and J. Galle in Max/MSP, which is a graphical programming environment to create software using a visual toolkit of objects. The basic environment that includes MIDI, control, user interface, and timing objects is called Max. On top of Max are built object sets

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such as: MSP, which is a set of audio processing objects that enable interactive filter design, hard disk recording, and Jitter, a set of matrix data processing objects optimised for video and 3D graphics.

The interactive environment has been developed for transcribing the movement of the body into 3D-space based on SpaceCustomiser [1], which has been developed by H. Bier in 2005: SpaceCustomiser can be seen as the Modulor [2] of the Digital Age, since it establishes relationships between the human body and the architectural space. As a system of proportions Modulor uses measures of the human body in architecture by partitioning it in modules according to the golden section and two Fibonacci Series. It puts, basically, man as measure of architectural spaces, which SpaceCustomiser does as well in a more drastic manner, since it generates 3D space by following the movement of the body in space based on ergonomic principles.

While Modulor applies a 2D proportioning system, SpaceCustomiser employs a 3D, dynamic, space-generating system. If in this context can be talked about a paradigm shift based on the influence of digital technologies, than this shift can be described in the methodology: In opposition to modular, repetitive architecture developed by using grids and proportions based on functional and formal rules, curvilinear architecture is being developed by generating space through following the movement of the body in space.

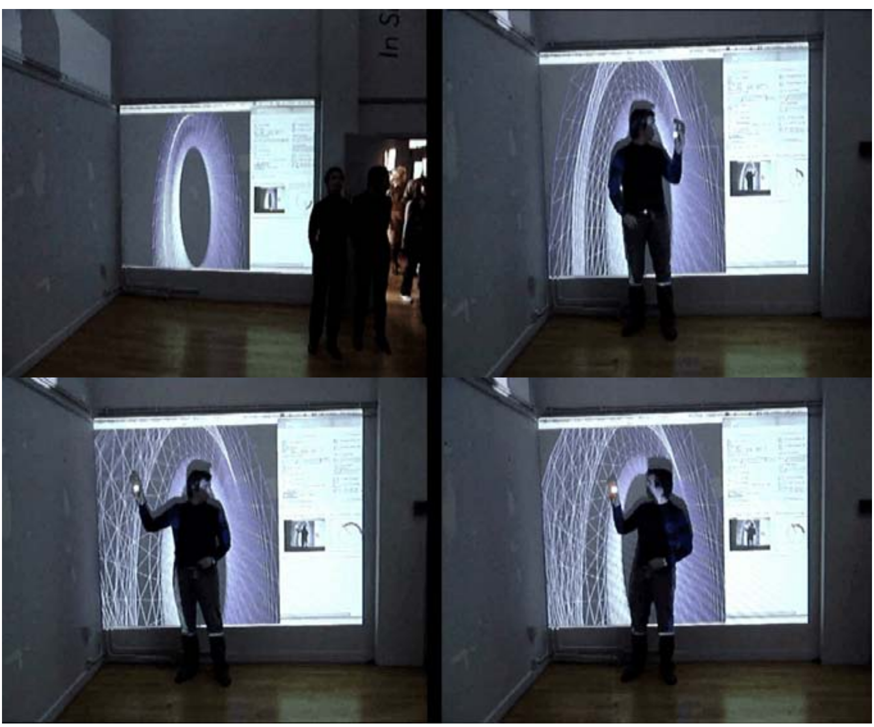

Figure 1: Deformation of the ellipsoidal cylinder.

2 Implementation

The initial space is an ellipsoidal cylinder, which represents the minimum space a standing person needs. This space has been divided in five segments, while the ellipse itself in divided in eight sectors. Each of the eight sectors is being activated, when movement in this area is detected. This means the movement of the arm to left/up triggers a deformation in the corresponding sector. The movement is being tracked by using a colour/movement tracking technique, which involves several steps: A camera captures the movements, while specific data is being extracted from the image sequence, for instance, an arm is tracked, while moving in space. This movement activates the spatial deformation in a direct way: A movement induces a proportional deformation of space. The space enlarges to accommodate the body in movement.

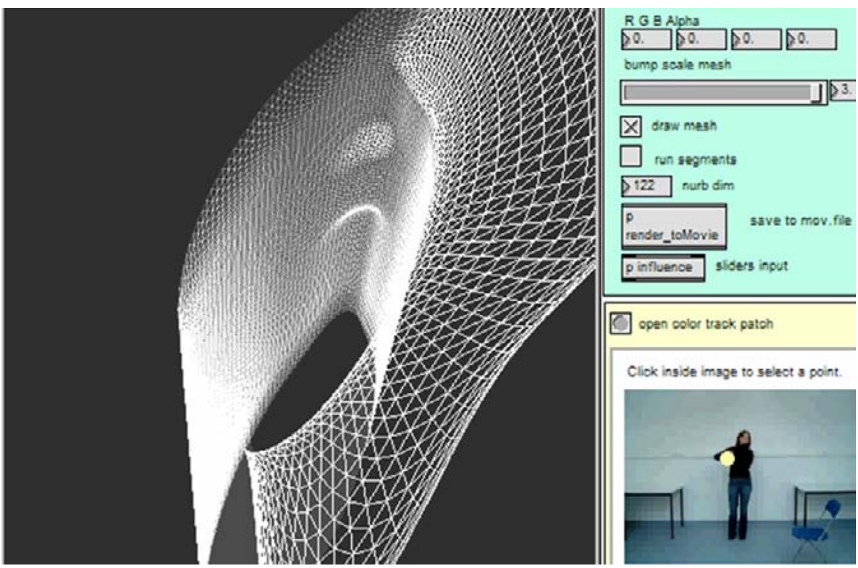

Figure 2: SpaceCustomiser: InterFace.

Geometrically speaking, the movement tracking is based on the conversion of the Cartesian coordinates of the tracked point into polar coordinates, while the deformation principle is based on NURBS, which is a mathematical model for generating and representing curves and surfaces. Editing NURBS-based curves and surfaces is easy: Control points are connected to the curves and/or surfaces in a way that their pulling or pushing induces a proportional deformation. While it is easy to manipulate NURBS surfaces by puling control points, the question is how to control this manipulation, which rules and design methodologies can be developed to control designs based on NURBS geometries? SpaceCustomiser proposes a NURBS-manipulation based on the movement of the body through space.

3 Programming

Max/MSP is a graphical programming environment for music, audio and multimedia, used to design cross-platform programs and user interfaces. Programming takes place in the Patcher window, where Max/MSP Objects, represented as boxes, are connected with patch cords. The program library includes several Objects to perform a wide range of tasks, from adding two numbers together to waveform editing, etc.

SpaceCustomiser: InterActive consists of three patches: 3.1 3D Shape, 3.2 Deformation, and 3.3 Movement Tracking.

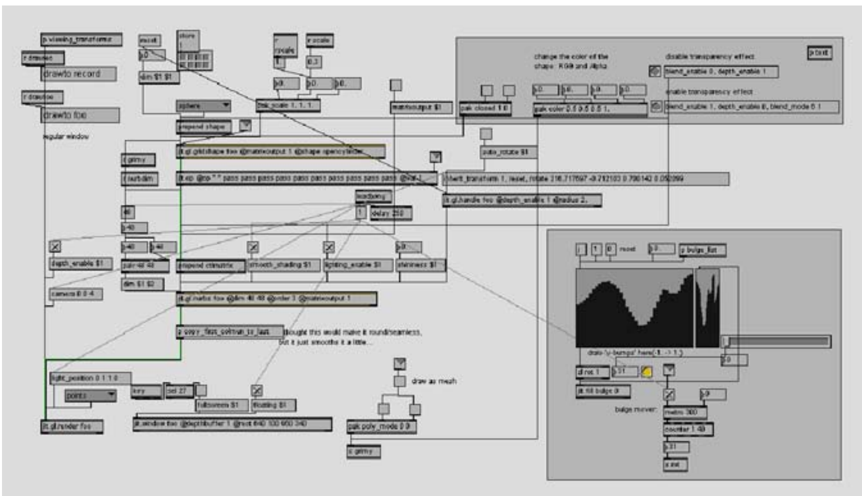

Figure 3: Programming: 3D shape and deformation.

3.1 3D shape

This patch implements 3D modelling in openGL. It is, basically, a rendering patch, enabling NURBS representation in real-time. The 3D shape itself has been developed by following a more steps procedure: The *jit.gl.nurbs* object has been used to generate the cylindrical shape, from which the ellipsoidal cylinder has been derived by scaling it down to 1/3 in the y-direction. An 8 x 5 *jit.matrix* has been mapped onto the control points of the NURBS surface, in a way that the cylinder is divided in five sections and each section is subdivided into eight sectors. This enables an accurate implementation of shape deformation according to the movement, since every subdivision can be addressed separately. How?

3.2 Deformation

An initial displacement matrix establishes the way the movement is translated into shape deformation: The sections 1-8 of the ellipse are mapped into the displacement matrix in a way that a row represents the eight sections of the ellipse, while the degree of displacement of each section is shown in the corresponding min-max columns. For instance, the initial ellipse – I – is represented in the displacement matrix as corresponding to a middle value [Figure 4], while the deformed ellipse – II – is shown as an alternation between middle and maximum values of displacement.

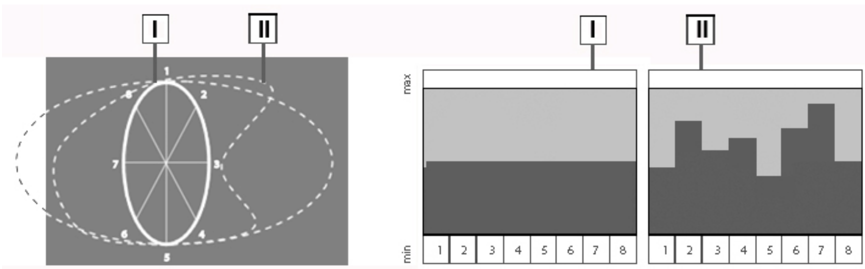

Figure 4: Diagram of the displacement matrix.

The displacement matrix establishes, therefore, how the movement of the body is being translated into spatial deformation, while the deformation of the ellipsoidal cylinder is implemented by movement/colour tracking.

3.3 Colour tracking

The movement tracking in real-time has been implemented by means of computer vision, which employs colour tracking performed with *cv.jit.track*, which is an external object for Max. It extracts xy coordinates from the movement and sends them to the Deformation patch, which in turn executes the shape deformation itself.

The colour to be tracked is being selected by clicking with the mouse in the video frame window, which shows the real-time movements captured with the camera connected to it. The Cartesian coordinates of the tracked colour/point are then converted into polar coordinates, which find their correspondence in the eight ellipsoidal sections.

4 Conclusions

This exercise in interactivity shows that the concept of responsive environments applied to architecture can be implemented in spaces, which dynamically react to the movement of the human body in space.

In this context, emergence and self-organization can be seen as principles on which interactive architectures can be based on, since building components dynamically adjust to their users needs. One of the modes of emergence and self-organisation in interactive buildings is based in space-customisation, as described in this paper.

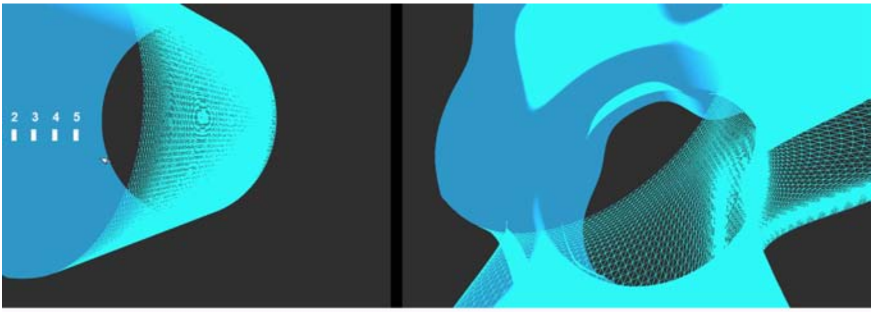

Figure 5: Five part segmentation of cylindrical space.

5 Perspectives

The next step in the development of this interactive prototype is the implementation of movement transcription not only on one segment of the ellipsoidal cylinder but on all five segments. For that, each segment of the ellipsoidal cylinder needs to be connected to push sensors on the floor, so that a forward movement of the body can be applied to the corresponding segment allowing transformation and deformation of space in three dimensions.

Furthermore, the pro-active potential of the space has been not yet explored: Following the example of interactive floors, which configure themselves as surfaces to lie and sit on, the interactive building components might follow principles such as 'store agenda and move accordingly' and/or might use sensor/actuator technology interacting with the environment according to the principle 'sense your proximity and react on it'.

In this context, architectural space based on NURBS can be understood as a space, which reconfigures itself according to the principle of swarms: Control points of NURBS can be seen as birds/boids [3] in a swarm, which configure themselves spatially according to preset rules, which accommodate the users' needs.

Acknowledgements

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A discussion of the term digital tectonics

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Abstract

For almost twenty years, digital architecture of different themes and characters has been produced. Through this time it has become possible to develop new and geometrically free forms, as well as calculate and simulate different technical matters of future constructions using digital tools. The wildest and most complex building concepts can through three-dimensional modelling and drawing programmes be realized and built, and this has naturally fascinated architects. Many digitally conceived projects are thus characterized by this fascination of the free-form geometry. In the contemporary discussions of digital architecture, digital tectonics is a commonly occurring term, and in this article the focus will be on this particular term. The term of tectonics has been used by architectural theorists for several centuries, but through time there have been many different opinions on what the term contains. In this article the term tectonics will first be defined through analysing of different architectural theories, and thereafter the term will be discussed in relation to digital architecture. Through this discussion a comprehension of the terms of tectonics and digital architecture is reached, and subsequently it is suggested how they together can form a new kind of tectonics – digital tectonics.
Keywords: tectonics, digital tectonics, digital architecture, performative architecture.

1 Introduction

During the recent decades Kolarevic [1], digitally designed buildings of different themes and characters have been produced. Through this time, it has become possible to develop new and geometrically free forms, as well as to calculate and simulate different technical matters of future constructions. The wildest and most complex building concepts can through three-dimensional modelling and

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drawing programmes be realized and built, and this have naturally fascinated architects. Many digitally conceived projects are thus characterized by this fascination of the new kind of shapes. Now, however, the digital tools have been used for a couple of decades in the architectural sphere, and the first fascination of the new geometrical possibilities is decreasing. Therefore it is interesting to take a look at the state of digital architecture, and evaluate what has come out of the use of digital tools until now. In the contemporary discussions of digital architecture, *digital tectonics* is a commonly occurring term.

The term of *tectonics* has been used in architectural theory for several centuries, and the word originates from Greek culture and language, where it has two main meanings in the area of architecture; the theory of the inner structure of a work of art, and the shaping and joining of form-elements to a unity. Through this time, several theorists, such as Karl Bötticher, Gottfried Semper, Eduard Sekler, and Kenneth Frampton, have discussed the term of tectonics. The main point from Bötticher's treatise on tectonics is, that every work of architecture, can be divided into Kerneform and Kunstform; the structural and the representational (Hartoonian [2]). Tectonics is according to Bötticher the system or concept that ties all the elements of a building together to a whole (Frampton [3]). Semper, too, makes a division between the technical and the symbolic issues, but also puts focus on the importance of coherency between material, and method of manufacturing. He divides the building into four fundamental elements; the hearth, the earthwork, the framework, and the screen wall, which are all either technical or symbolic (Hartoonian [2]). Furthermore, Semper regards the knot as being the oldest and most original constructional part (Frampton [3]). Therefore the joint is crucial for Semper, and in his opinion, it is out of the transitions between building elements, that the beauty of architecture emerges. Frampton proposes that tectonics is a means to reveal the essence of a building. Therefore he suggests logic constructions, in order to clarify the structure of a piece of architecture, and make it immediately understandable. Also in Frampton's theory the joint has a prominent place – the joint is where elements and materials meet, and it is therefore a crucial point in the telling of the logic of a construction. In the joint, the story of materials, overall structure, and laws of nature is embedded, and it thus the most tectonic element of an architectural artefact (Jameson [5]).

When considering the terms *digital* and *tectonics*, one might come to the conclusion that they are contradicting each other (Leach [6]). The digital is comprehended as virtual, abstract and free of the laws of nature (Liu *et al.* [7]), while tectonic is tactile, concrete, and, as earlier described, arising as a reaction of the laws of nature. Therefore it might immediately be difficult to see, how these two can be combined, and how one at all can speak of such a term as *digital tectonics*. What might then be contained in the term of digital tectonics? Just as in the case of tectonics there are numerous of different opinions on how the term of digital tectonics should be interpreted. One of the suggestions of how to describe the term digital tectonics is *"the poetics of digitally conceived, structurally clarified and directly manufactured architecture"* (Jabi [8]). At times the description is even reduced to *"the poetry of digitally constructed* *assemblages"* (Jabi [8]), but the question is how it then relates to the traditional meaning of tectonics. Where in a piece of digitally conceived architecture is one supposed to look for the concrete signs of digital tectonics? This article contains analyses and reflections on the term of digital tectonics. Through presentation and discussion of existing theories on tectonics and digital tectonics, an understanding of the similarities and discrepancies between the two matters of are proposed.

2 Digital tectonics

The new techniques and tools that are available through computer programmes can both be used in an aesthetic manner, to handle complex compositions of shapes, but also in the engineering area, as described in the previous section on optimisation, which makes it is possible to find precise solutions through complex models of the building and its conditions. These new possibilities in terms of complex visual and spatial systems have enabled architecture to remain abstract, often at the expense of construction and materials (Beesley and Seebohm [9]).

The new possibilities of digital creation of geometrically free forms are today inspiring many architects to build curvilinear. The stylistic break caused by the emergence of digital tools, has thus resulted in architecture that seemingly rejects the notion of structural technology, continuity, and morphology. The architects of this movement represent an ideological, conceptual and formal break with the building tradition (Kolarevic [1]), and use the classical, or representational, approach to architecture. One of the architects that can be placed in the classical appearance orientated digital architecture is Frank Gehry (Leach [6]). Gehry preferably uses a tactile physical model, instead of a digital manipulation of surfaces on a computer screen. Therefore his use of digital technologies can be seen as a translation of physical models, into digital information that can be used in the final fabrication of the building (Kolarevic [1]). In many cases the computer has been used to replace the manual tools of the architect – the drawing board, the clay-model, the slide rule etc. – in the production of traditional architectural drawings. Hereby one of the major advantages of using the computer is neglected; the possibility of generating geometric forms that are not directly controlled by the designer. Greg Lynn is one of the first architects to use animation software for generating form, instead of generating representations of future buildings; for instance force fields were used to generate and transform structures (Kolarevic [1]). As an example of this method of working can be mentioned Bernhard Franken & ABB Architekten's *the BMW Pavilion* from 1999 (Figure 3). The formal foundation of this building is two spheres lying apart from each other. A force field, drawing them closer to each other, is added to the scene. The spheres start to move and eventually they melt together into a unified form. This method can be used for both generating completely free form, but if placing force fields in the scene that relates to the character of the site or actual loads on the building, such as wind-loads, the generated form will get more project-specific and begin to relate to the term of tectonics.

In the area of technological aspects of a building – such as construction, acoustics, lighting, climate, etc. – the digital tools provide great possibilities for exploration and simulation of future conditions, as well as engineering optimisation, as mentioned in last chapter. In the *City Hall* of London, drawn by Foster and Partners, there are for instance made solar studies, to investigate how the sunbeams will be distributed over the building's surface, and different shapes are tested in relation to the acoustics of the interior, before the final shape of the building is found (Whitehead [10]). With these kinds of possibilities of conducting research before actually building a piece of architecture, the expectations on building design are redefined. The demands are getting higher and there is a new emphasis on building performance, for example in relation to economics, spatiality, culture, ecology, and technology (Kolarevic [1]).

Another example that can be mentioned is the National Swimming Centre drawn by PTW Architects in 2003 for the Olympics in Beijing 2008 (Figure 3), in cooperation with Arup Engineers and China State Construction Engineering Cooperation a+u [11]. The concept is based on the three-dimensional structure of water foam, which defines both the constructive and spatial system of the building AV [12]. Thus the building can be explained as a cube of water molecules, in which there are carved out spaces for different functions – a watercube.

As implied in the examples of *the BMW Pavilion,* London *City Hall* and *The National Swimming Centre* the generative processes can be opened up to the new conceptual, formal, and tectonic possibilities of exploration that lies in digital tools, with focus on the adaptability of form. Hereby the digital tool provides what seems to be the notion of the digitally based techniques – the shift from *making of form* to the *finding of form* (Kolarevic [1]). When using the word *finding* in this context, it is not meant to suggest that the optimal shape is supposed to be found and copied directly from a technical computer programme. Such a solution is called a *mechanical* solution, as the architect would not have any influence on the completely computer-generated result. To reach a tectonic result, a *machinic* solution must be found, i.e. the process must contain computational technical aspects as well as architectural aesthetic considerations (Leach [6]). The computer is then used as a collaborative partner, that give the architect technical guidelines through the process.

With offset in both the aesthetic and the technical sphere Branko Kolarevic introduces the concept of *performative architecture*. This is a term signifying architecture that should perform especially well in some areas, such as acoustics, indoor climate, or construction, and therefore needs analysing on the matter, and accordingly adaptation of the architectural form (Schmidt [13]). When bringing the technical and the representational aspects together in a process where the technical analyses are allowed to be highly influent on the shaping of a building, the process will have great tectonic potential. Philip Beesley and Thomas Seebohm also relate to both the ontological and the representational, when arguing that digital tectonics is *"a systematic use of geometric and spatial ordinances, used in combination with details and components directly related to contemporary construction"* (Beesley and Seebohm [9]). Hereby they suggest that the architect should work with geometrical structures, as a foundation, or main idea, for the building, and then use the knowledge and technologies available to communicate these notions and structures trough the concrete design of details and components. Neither Kolarevic's nor Beesley and Seebohm's suggestions is very different from the earlier descriptions of tectonics in relation to the interaction between construction, material and expression, but there is a new emphasis on *téchne* in relation to the process, through which a project is being shaped, and the knowledge and use of new technologies and tools. It is here that the digital tectonics can be found – in the unified process where the architect turns into a modern *tekton*, who can overview and control all, both technological and aesthetic, aspects of the building.

3 Clarification of the term of tectonics by examples

In the following, three architectural works (Figure 1) will be evaluated in relation to tectonics, in order to get a more concrete comprehension of the term, and to define the discrepancies and similarities between the earlier mentioned theorists – Bötticher, Semper, Sekler and Frampton. To get a comparable result of the discussions, the main points of each theorist is pinned up in a table, which is filled out for each of the architectural works (Figure 2). The buildings are evaluated trough the table and get a green dot, if they fulfil the main points of the theorist, and red dot if they do not. The first building is Ludwig Mies van der Rohe's Barcelona Pavillion of 1929, hereafter follows Jørn Utzon's Bagsværd Church of 1977, and last Jean Nouvel's Institute du Monde Arabe of 1987. These three buildings represent different movements of the last century and thus also different approaches to tectonics.

Figure 1: Pictures of the buildings used in the comparison. From right to left – Interior of Bagsværd Church; Exterior of Barcelona Pavilion; and the façade of Institute du Monde Arabe.

From (Figure 2) it is clear to see, that the theorists do not quite agree on what tectonics is. Therefore it is interesting to find out whether or not there is a centre of interest that the theorists have in common. To start with, all of the theorists suggest a division of architecture into a concrete part and a more abstract part. To the concrete part belong construction, method, and material, whereas in the abstract part belong structure, concept, representation, and intensification. Semper and Frampton primarily proposes that the concept of a building is told through the transitions – the joints, while Bötticher and Sekler is more general in their suggesting that the construction is articulated by respectively a unifying concept, and intensification by tectonics.

BÖTTICHER Keywords: Structure and symbol / Unifying concept	SEMPER Keywords: Material and method / Details and joints	SEKLER Keywords: Structure and Construction / Intensification by tectonics	FRAMPTON Keywords: Clear structure / Elaboration of joints
✔ **The Barcelona Pavilion** There is a delicate balance between structure and symbol in the Barcelona Pavilion. The symbols are embedded in the materials of the building elements, and the beauty lies in the small details. The concept is built upon the modernistic thoughts of illusive spaces and volumes and this is carried out through the whole construction.	● **The Barcelona Pavilion** The materials and methods of manufacturing are coherent and much of the quality of the building lies in the choice of materials. The transitions between elements are kept very simple, but they are very well articulated, in relation to showing the transition of forces.	● **The Barcelona Pavilion** The structure and the construction are coherent, and the construction is working according to the main concept, but the construction is not immediately comprehensible, as the transitions of forces between the building elements are not visible. The intensification by tectonics is apparent throughout the building, as all details is working in favour of the modernistic concept.	● **The Barcelona Pavilion** The construction of the building is simple and is in itself quite logic. The joints, however, are not telling the story about the logic of the construction; the columns are rather floating between the roof and the floor and one cannot conceive a transition of forces in the joint between them. They do though tell the story of the concept and thus reveal the essence of the building in a less technical manner.
✔ **Bagsværd Church** In Bagsværd Church both the structural and representational parts are clearly articulated. The concept for the building is also clear and construction and symbol melts together to a whole.	✔ **Bagsværd Church** The transition from wood to concrete (Semper´s Stoffwechseltheorie) has been handled with care. The undulating ceiling, however, might have been more simply manufactured in metal truss work. The overall structure is an illustrative example of Semper´s hearth (alter), earthwork, framework, and screen wall. The joints between the different elements are simple and clear and one can thus understand how the building is coping with the forces.	● **Bagsværd Church** There is consistency between the structure and the construction in the framework of the building, but as earlier mentioned, the ceiling might have been more simply constructed in metal truss work. There is though an intensification of tectonics, for example in the merging of the columns into the strengthening screen wall.	✔ **Bagsværd Church** The structure of the church is clear and comprehensible and the joint are well elaborated. One can understand the logic and the symbolic concept of the building, when experiencing it.
● **Institut du Monde Arabe** The representational jalousies are dominating and obscure the structure of this building, at least when thinking of the force-resistant structure. There is a clear unifying concept through the techno-Arabic theme, and the structure and the symbols are separated, so that they can be conceived individually.	✔ **Institut du Monde Arabe** The way, in which the Islamic ornament is transformed into an electronic aluminium screen, is an excellent example of Semper's Stoffwechseltheorie, and one must admit that Nouvel uses the materials and methods according to their qualities. Also the details are delicately elaborated – simple and coherent.	✔ **Institut du Monde Arabe** The structure is frame-curtain wall, and the construction is clearly showing the curtain wall, whereas the framework is only seen in some parts of the building. The intensification by tectonics is indeed present in the building, where the elaborate aluminium composition takes up of much of the attention.	● **Institut du Monde Arabe** The structure is not immediately comprehensible, at least not seen from the outside. One can understand that there is something, force resistant behind the screen, but it is not possible to see what it consists of. The joints are beautifully detailed, in a simple and delicate manner.

Figure 2: Table containing evaluation of three pieces of architecture in relation to four theorists – Bötticher, Semper, Sekler and Frampton. Tectonically correct ✔ Tectonically incorrect ●.

Looking chronologically on the development of theory on tectonics, one can through the four mentioned theorists see a moving towards an emphasis of clear and comprehensible construction. This might be a reaction to the abundance of materials and construction types available today. With the emergence of computer technology it is made possible to couple almost any material with any constructions, as constructions can be dimensioned in detail, before building them, and materials can be modified and appropriately reinforced, in order to meet the demands of the architect.

4 Clarification of the term of digital tectonics by examples

In order to find similarities and discrepancies in how the concepts of *tectonics* and *digital tectonics* are being comprehended an evaluation – similar to the comparison of buildings in relation to tectonics – of three digitally conceived works of architecture (Figure 4) is done. From the previous discussion on the term of tectonics to central issues are picked out: *Material and construction / Structural logic.*

Neither the term of digital tectonics is divided into any sub-categories. Because the term digital tectonics is relatively new, there are no such established and elaborate theories on the subject, as there are for traditional tectonics. Therefore some general keywords on the matter of digital tectonics are picked out from the discussion of the previous pages: *Performative architecture / Clear and logic structures*.

The buildings that will be evaluated with offset in these keywords are *Walt Disney Concert Hall*, in Los Angeles, by Frank Gehry; *the BMW Pavilion*, by architects Bernhard Franken and ABB Architekten; and the *National Swimming Centre*, by PTW (Figure 3). These represent widely different approaches to the new possibilities given by the emergence of digital tools.

Figure 3: Three digitally designed and built buildings – Walt Disney Concert Hall, The BMW Pavilion, and the National Swimming Centre.

From these comparisons it is possible to distinguish the differences between the traditional and the digital tectonics, as it is comprehended today. Only by looking at the chosen keywords one can see, that the first discrepancy; traditional tectonics is more tangible and concrete, with its emphasis on detailing in relation to the used materials and constructions, whereas digital tectonics emphasises the iterations and interaction between aesthetic and technical aspects in the form-finding process and is thus more abstract and process oriented. Having said this, the first similarity is as well apparent. Both the traditional and the digital tectonics is clearly a way of expression the fusion between art and technology – the phenomenological and the positivistic. This is the core in the definition of tectonics, explaining what the concept of architecture is all about. The art of building is an art form that arises as a response to context, science, and forces.

TECTONICS Keywords: Material and Construction / Structural logics	DIGITAL TECTONICS Keywords: Performative architecture / Clear and logic structures
Walt Disney Concert Hall The sheet metal cladding of the facades are a logical choice for the desired expression and construction as it is formable and relatively light. The inner structure is technically logic, but it is not displayed to the observer in order to make the building comprehendible, but is rather considered a hidden means to achieve the desired sculptural expression. Therefore the structure and material of the bearing and stabilising construction have no impact at all, on the expression of the building.	**Walt Disney Concert Hall** The actual concert hall is highly performative architecture, and has also been treated as such. The acoustics is thoroughly investigated and the shape is adjusted according to the results of the technical analysis, with aesthetics and technology working together. The structures are, as earlier mentioned, logic, but cannot be considered to be clear, as they are hidden behind the sheet metal curtain walls.
The BMW Pavilion The structure is logic, in relation to the strong geometrical notion that is chosen for the building. Even though the desired geometry dominates the process, the chosen materials prevents the geometry to obscure the structure in the realized building. The materials and the construction are well chosen for the purpose, The details are elaborate and simple in order to express high-quality finish and elegance.	**The BMW Pavilion** The performance of the architecture is here tied to the spatial and expressive aspects, which entirely define the shape and the constructions. The geometry is found and hereafter the bearing structures are designed to suit the sacred shape. Therefore there is no mutual impact between the shape and the results of the technical analyses. The structure can be considered be applied to the sacred form, as a subordinate element, and thus it rather works *for* the shape, instead of *with* it. The construction is simple in order to submit to the shape, rather than being clear, in order to show the logics of the forces. The lack of interaction between technology and representation during the proces makes the BMW Pavilion digitally atectonic.
The National Swimming Centre The materials and the construction are inseparable - it would be possible to build the construction with other materials than those, that are used. The structures are created from the water foam concept, and is then transformed into a building construction. It is geometrically logic, and understandable, through the bubble metaphor.	**The National Swimming Centre** The building has been developed through investigation on how the water foam structure can act as constructive and spatial system as well as facades. The result of these investigations is a logic and poetic interpretation of water foam.

Figure 4: Table containing evaluation of three pieces of architecture in relation to tectonics and digital tectonics. Tectonically correct Tectonically incorrect .

In the case of the *BMW Pavilion*, the whole geometry is generated and chosen, with offset in models, which have neither materials applied, nor thickness of the surfaces – it is purely given its shape from aesthetic considerations. Surely there are forces in the scene, that helps generating the geometry, but those forces are, positivistically speaking, arbitrary forces, as they are chosen and inserted by the designer. Even gravity can be considered an abstract force in a model without material properties, and is therefore also a matter of aesthetic choice of the designer. There is not necessarily a logic hierarchy of the applied forces in relation to the real laws of nature, i.e. the conceptual attraction of the two spheres in the *BMW Pavilion* is equal to the force of gravity in the digital world.

In relation to the *Walt Disney Concert Hall*, the shape is in some ways aesthetically chosen, without considerations on the technical aspects, especially not the actual bearing of the hall, but the geometry is not holy, and can thus be changed in relation to the technical analysis. The basic shape is also impacted by the acoustical experiments from the early phases of the design process. Even though there have been technical considerations and analyses during the design process, the aesthetic shape is most certainly obscuring the structures of the building. The forms of the building do by no means disclose how the building is born and stabilized. The sheet metal gives the building a sculptural and shell-like expression, but the underlying construction is actually a lightweight latticework of steel. This is a very atectonic aspect of the building, as it is not possible to experience the flow of forces through building elements and joints. The new CAD/CAM technologies have made these complex constellations possible, but unfortunately, the elegance and preciseness of the constructions that the techniques enable, are not a part of the building's expression.

When looking at the process from which the *National Swimming Centre* has been designed and produced, it is clear that technology and aesthetics have worked together, in order to create a unified whole. This is a good example of performative architecture. The process gives rise to a lifting of architecture to a higher level – a level where the building can both be technically correct and artistically handled. The results from technical analyses are constructively and artistically worked into the design, and they are therefore an important design parameter, rather than an appliquè to a form. The process is hereby a hybrid-process, with architects and engineers working closely together in a digital continuum. PTW has used the computer technology to create unconventional architecture, by using nature to find a system that is transformed into a building system with help from the computers. Hereby they redefine and challenge the traditional building elements, walls, columns, window etc. At the same time, they use a system that we humans recognise as porous and stable – foam – that makes the building seem both logic and poetic.

Considering these different aspects of the digital and the tectonic, it is suggested that the digital tectonic should arise as mixture of the concrete and the abstract. The traditional term of tectonics is not quite enough, when evaluating digitally conceived architecture, as it does not detect the atectonic process. The tectonic process have become more relevant, since the emergence of computers, as it is now possible to create a logic construction to each and every desirable form, as seen in the example of the *BMW Pavilion*. On the other hand, the digital tectonics, as it is described through the keywords in the comparison, does not mention the relation between construction and material. This should, as Heidegger [14] points out, be the corner-stone in all aesthetics, and the interaction between construction and material is obviously an important aspect of revealing the truth of the nature of loads, forces and material properties – in it lies the whole comprehension of what it means to construct and build. Thus it is proposed that the central issues in terms digital tectonics should be: *Interaction between material and construction, Clear and logic structure, Performative architecture.*

5 Conclusion

Through this paper the terms tectonics and digital tectonics have been discussed in order to find out how they can be comprehended, and how they can be used in the architectural field today. Tectonics has been used in architectural theory for several centuries, and the term both refers to the concrete and the abstract aspects of the art of building. The main issues, contained in term tectonics, are suggested to be *the interaction between material and type of construction*, and *the communication of the logics of the chosen structure*. The former of these relates to the ontological aspects of building, and the latter to the representational. With the emergence of digital architectural tools, it is interesting to see how the architects are using the new technology to change and improve the art of building. From the mentioned examples of digital architecture in the second and fourth section of this paper, it can be seen that the computer technology is used vastly differently by different offices. From looking at the processes, it is suggested that it is possible to reach a tectonic result, without having had an integrated and tectonic process, such as in the case of the *BMW Pavilion*. It is possible to find a logic structure and construction to every, desired and thinkable, geometry, without even once considering it in the form-finding process.

For the last decades it has also become possible to compose materials, with almost any thinkable properties combined. This in some ways changes the logics of construction, and therefore also the logics of tectonic structures. At the same time, the computer technology makes it possible to create structures that would have been impossible to manage before, as seen in the *Walt Disney Concert Hall* and *National Swimming Centre*. In the latter of these two pieces of architecture, the constructive and the spatial systems are intrinsically connected, and through this artistic and spatial interpretation of the laws of science and nature a tectonic poetry arises.

The new tectonics is though not just the challenging of the old building traditions and techniques, but also a matter of an integrated process. Digital tectonics is thus not just an addition of digital architecture to the traditional term of tectonics. It is a new way of considering architecture, as a clear and logic result of a hybrid-process. The deeper meaning of architecture and tectonics is still the same – it should still reveal the truth of the building and its context. The technical context is however changed because of the new possibilities that lie in the digital tools, and thus the notion of tectonics also has to change. Therefore Bötticher, Semper, Sekler, and Frampton's definitions of tectonic are not sufficient anymore. Another aspect has to be added – *an integrated form-finding process*. On the other hand, digital tectonics, as it is described through the keywords in the comparison, does not mention the relation between construction and material. The interaction between construction and material is an important aspect of revealing the truth of the nature of loads, forces and material properties – in it lies the whole comprehension of what it means to construct and build. It is therefore suggested that digital tectonics is a combination of *Interaction between material and construction, Clear and logic structure,* and *Performative architecture.*

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Form follows idea: ideation and CADCAM

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Abstract

In the mid 1990s, we have seen the computer impact the architecture process in the area of 3D modeling and "visualization;" however, this 3D phenomenon, until very recently, has generally been confined to "marketing" presentations in the form of renderings and animations. In architecture, most design studios have remained isolated from the computer, typically using 2D free-hand drawings on traditional paper based media. Many have claimed the computer is a hindrance to creativity; however, some at the forefront of creativity, with technology, see the computer as not only a making "tool" but also a design "partner" in form ideation and conceptualization.

This paper will analyze the advanced "digital design" process used by the writer's student in a graduate level Digital Design II course. The student entered our "post-professional" graduate program as a means of learning more about design, technology and architecture. This provided an opportunity to do research in the area of digitally driven form concepts. For the inquiry, the student chose to use the "skyscraper" as a means of exploration for digital form generation. The student's concept, the "female-human figure" was only feasible to translate into architectonic form using digital design techniques via 3D free-form "virtual" modeling and 3D printing "physical" modeling output. CADCAM tools proved to be empowering for the student's exploration, learning and design creativity.

With the recent emergence of both more user-friendly hardware and software, we are seeing a paradigm shift in design "ideation." This is attributed to the evolving human-computer-interface (HCI) that now allows a fluidic means of creative design ideation, digital representation and physical making. Computing technology is now infusing early conceptual design ideation and allowing designers, and form, to follow their ideas.
Keywords: design, design ideation, digital design, computer-aided-design, computer-aided-manufacturing, CADCAM, representation, visualization, virtual 3D models, physical 3D models.

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1 Introduction

Early architectural computing theorists conceived of "rational" applications of computing in architecture; during this early period of the 1960–1970s, this was quite natural as one-dimensional (1D) binary "text and numbers" were the primary output capability of early computing. This "rational" attitude coincided with "systems thinking" and scientific "numerical computation" which represented the forefront of technology during this early era.

During the 1980s, we saw the emergence of basic computer graphics, this influenced architecture primarily in the area of two-dimensional (2D) representations, and hence the adoption of "digital" drafting techniques. This twenty year old phenomena has remained dominate in mainstream architecture which, in the words of Michael Hammer [1], "paved the cow-paths" by accepting the digital "automation" of traditional design "ideas" and representational strategies.

In this evolving process of architecture, areas of discrete "islands" have maintained autonomy; these areas are primarily noted as 1) conceptual ideation, 2) visualization 3) production 4) construction and 5) operation. The area of "construction (i.e. making) includes a myriad of complex representational "drawings," and recently emerging 3D "representations," in order to actually "construct" a building. It is now well established that a major paradigm shift is occurring based on the ubiquitous immersion of 3D modeling in all phases of the process of architecture (i.e. design-build-operate) [2–4]. This very complex topic, often referred to as Building-Information-Modeling (BIM) is well beyond the scope of this paper. For the sake of brevity, this paper will focus on early conceptual design ideation.

2 Design thinking

In architecture, both in practice and pedagogy, most design studios have remained isolated from the computer, typically using 2D free-hand drawings on traditional paper based media. With the recent emergence of both more user-friendly hardware and software, we are seeing a paradigm shift in design "ideas." Where many have claimed the computer is a hindrance to creativity, some at the forefront of technology see the computer not only as a "tool" to make their ideas, but also as a design "partner" in form ideation and conceptualization [2, 5–7].

Heretofore, 3D digital models have generally been used as a "representational" tool for a pre-conceived "idea" that was generated prior to the intellectual or physical engagement of the computer. Often, designers have complained the computer "confines" their ideas and traps their "ideas" inside "the box," (i.e. the flat screen 2D world of the monitor) [8, 9]. However, as we will see, this problem is being overcome via recent hardware and software developments; additionally, we are seeing a "new" generation of computer users emerge who embrace the "holistic" integration of digital thinking in their design process.

3 The design problem

The design problem was established in the context of a graduate level course entitled *Digital Design II* taught by the writer in spring 2006. The primary focus of the course is the pursuit of digital ideation and making in architecture using emerging technology. This paper will highlight the work of one of the student's who entered our "post-professional" graduate program as a means of learning more about design, technology and architecture. This provided an opportunity to do research in the area of digitally driven form concepts.

Each student in the course is challenged to develop his or her personal "research" and "inquiry" problem for the semester project. For this proposed inquiry, the student chose to use the "skyscraper" as a means of exploration of digital form generation. Each student was required to do research in their topic area of choice, this being done to gain insights from history as well as evolution into the contemporary context. The student was particularly attentive to architectural designers who are currently regarded as leaders in area of technology and "skyscraper" design (see Figure 1).

Norman Foster
Swiss Re Building

Santiago Calatrava
Tower at Malmo

Rem Koolhaus
CCTV Headquarters

Figure 1: Skyscraper - form and technology.

4 The design process

The student developed an understanding of the urban context and the issue of world population demographic shifts as we see a shift from agrarian to urban societies. The "skyscraper" was proposed, not unlike earlier "modernist" architects, as a response to transportation and the need for density for amenities offered in the urban context. Thus, the student initiated their representational strategies first in reading, thinking and writing in both numeric and text to generate 1D output. Thereafter, the student began a series of diagrams and sketches that depicted their progressive understanding of the "problem" and the "skyscraper" as an elemental system of core, floor, and skin (see Figure 2).

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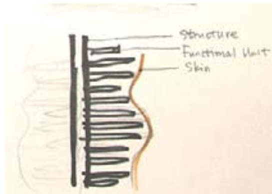

Figure 2: Major elements of a skyscraper.

Figure 3: Concept – female human figure.

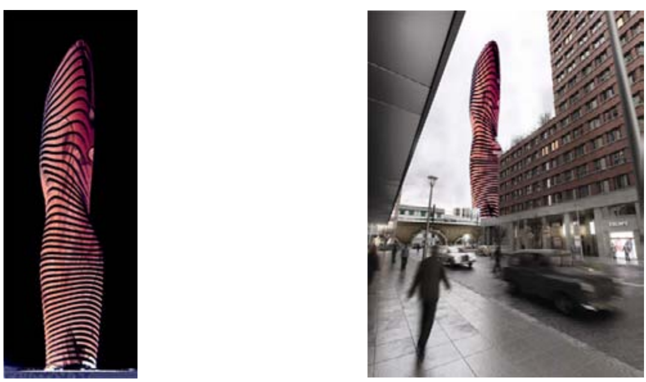

Figure 4: Concept - architectonic development.

Please note that the student used marker or pencil on paper (i.e. traditional media); this particular student has a laptop computer and has tried an external “wacom” tablet; however, the student prefers the direct contact of hand-eye motor interaction of traditional media. About 50% of our students have PC tablets and are finding significant “comfort” with the digital “free-hand” drawing tools. This area of Human-Computer-Interface (HCI) is very important and will continue to have increasing impact in early ideation representation; however, this is beyond the scope of this paper. Most important to this discussion, we do not dictate any media to the student in the course; we offer a plethora of media, both traditional and digital strategies, for both 2D and 3D output. We feel this pedagogical position of using the advantages of "all" media to be empowering to the student. Additionally, from a research standpoint, we feel we must be open to all design and media strategies to be unbiased in our scholarly pursuit of digital design methodology. The student's concept evolved into the abstraction of a "female-human figure" (see Figure 3). Pursuant to the 2D paper based media sketches, the student then moved into the digital realm and generated a 2D "free-form" digital reinterpretation of the concept using Photoshop (see Figure 4).

The student then began another series of digital 2D diagrammatic studies using both line and color as visualization aids in AutoCAD. Thereafter, the student began a series of 3D digital models to analyse the form (see Figure 5). An additional series of 3D digital models were generated to study the form proportions in the "virtual" environment using Rhino. Following this analysis, the student then began a series of small "physical" models studies, using the Rhino digital models and a ZCorp 3D printer (see Figure 6).

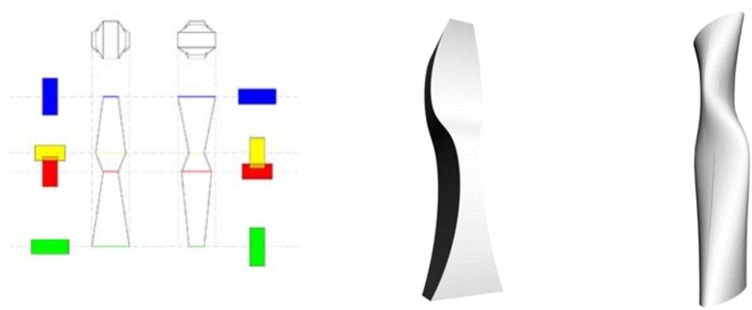

Figure 5: 2D and 3D digital form studies.

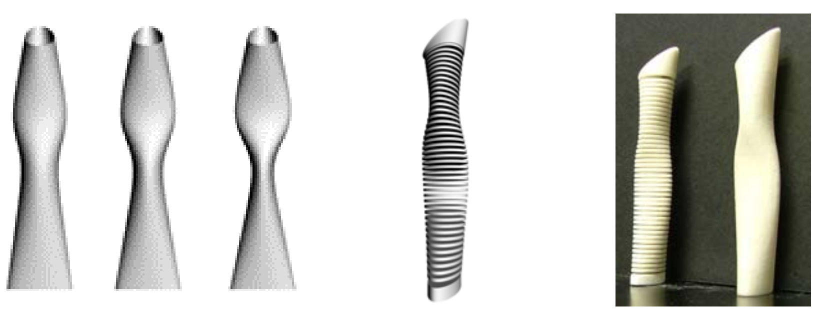

Figure 6: 3D virtual to 3D physical model studies.

Following this series of shape and proportion studies, the student then began analysis of structure and skin options. This led the student to a series of digital model studies, with subsequent 3D printed "physical" models to study the scale of a tubular "diamond braced" skin system (see Figures 7 and 8).

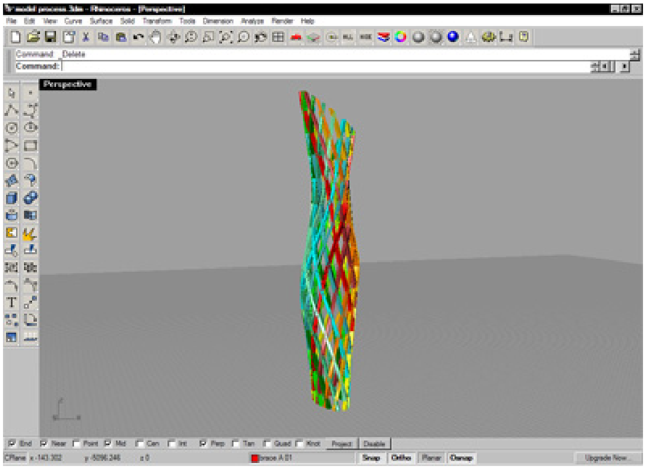

Figure 7: 3D virtual model - diamond skin.

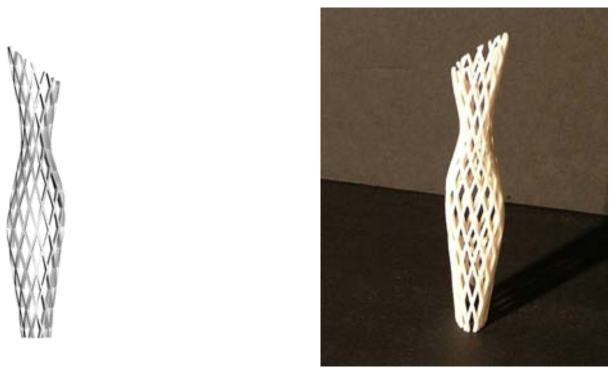

Figure 8: 3D physical model - diamond skin.

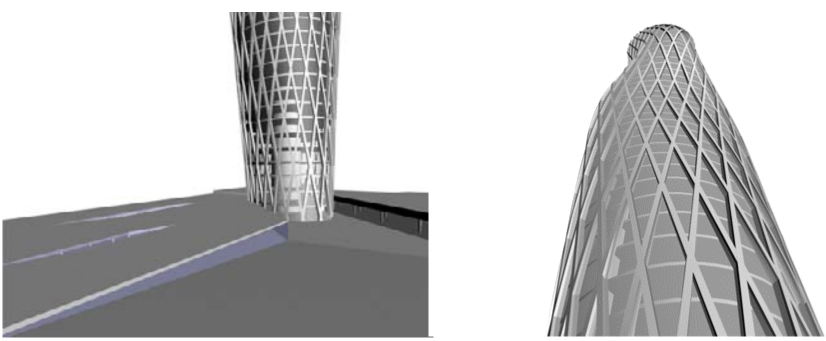

Figure 9: Virtual model output – 2D images.

The ability to migrate between virtual and physical models was invaluable for the development of the form (see Figures 7–9).

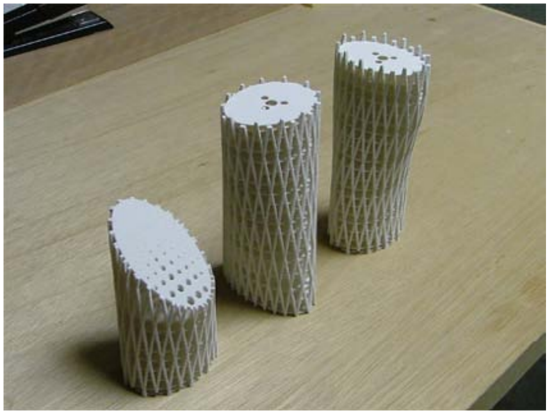

Figure 10: Skyscraper assemblage parts.

Figure 11: Physical site model – CNC routed.

The representational physical 3D printed study models varied in scale from 1:2000 to 1:500. The use of CADCAM allowed accelerated learning of representational strategies to the student; the act of "making" with the "machine" allowed iterative small "test" 3D models to be quickly generated for the student to analyze the appropriate amount of detail and information to be included in various scale physical models. Additionally, part of the challenge for the later developed larger 1:500 scale 3D printed models was the size constraints for output of our ZCorp 310 3D printer. Thus, part of the learning experience for the student was the challenge of how to CADCAM the elements of the skyscraper as a “kit-of-parts.” This required “parts and assemblages” thinking by the student, which we teach and feel to be relevant in the emerging paradigm shift in the “making” and “manufacturing” of architecture [10] (see Figure 10).

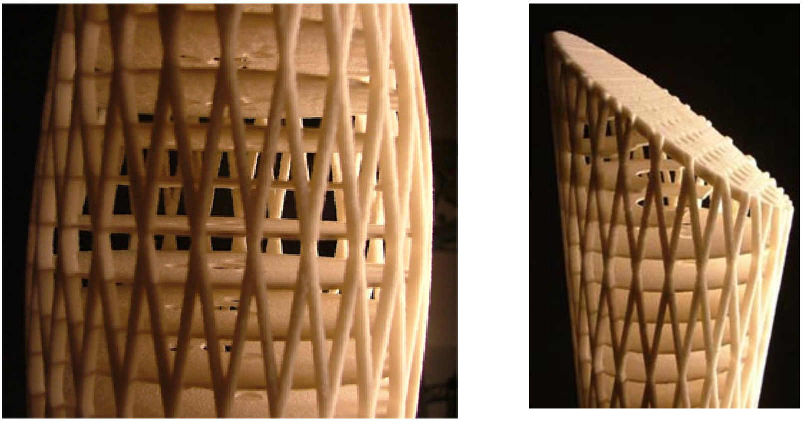

Figure 12: Physical model output – 3D printed.

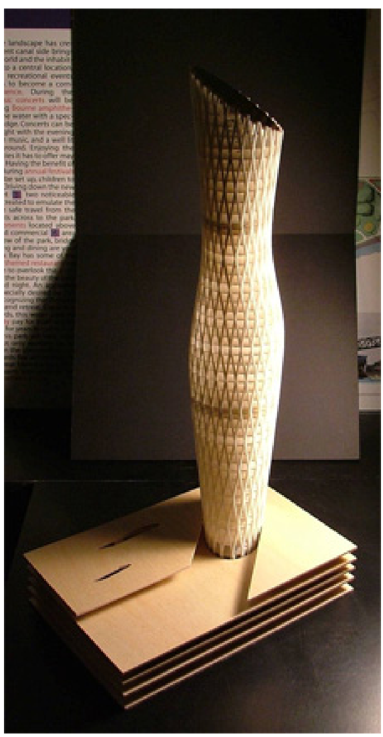

Figure 13: Skyscraper – *Sway Tower*.

A site concept was generated as well and a physical model was milled using a "DaVinci" Techno Esel CNC router (see Figure 11).

The larger scale 3D printed model at 1:500 allowed representation of the skyscraper floor plates as well as the proposed primary "diamond braced" skin support matrix (see Figure 12).

The CADCAM generated parts were then assembled to convey the student's idea in physical form (see Figure 13).

5 Conclusion

Our pedagogy and research has shown the visualization and representational power of emerging 2D and 3D CADCAM tools. Architectural form concepts, heretofore, impossible to model and represent, much less manufacture and construct, are now possible due to CADCAM. Emerging designers are integrating "digital thinking" in their fundamental conceptualization of form. These creative free forms are only feasible for translation to tectonic form using digital design-make techniques. CADCAM tools are empowering designers for form exploration and design creativity. Current computing technology is now infusing the creative design process; the computer is becoming a design "partner" with the designer and is changing form and architecture; thus, we are now seeing unprecedented design-make creativity in architecture.

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Formal complexity in Digital Architecture

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Abstract

This paper discusses Geo_Soft's relationship to issues of aesthetics, complexity theory and technology. Complexity theory will be discussed insofar as its relationship to architecture is concerned, which will then lead into a review of the difference between Representation and Performativity. The recent semiotic tradition associated with post modern architectural writers of the 1960–1980s declared that the meaning of architecture was lost during the modernist period and that architecture should not break with its history. Performativity has been extended beyond the meaning given to it by Judith Butler. More specifically, the issue of complexity aesthetics will be analysed historically and critiqued by unveiling the differences between Venturi's 'Complexity and Contraction' and Le Corbusier's 'Towards a New Architecture', concurrently with the recent discourse regarding Performativity. A grading system for defining complexity will be explored by reference to the theory of the Edge of Chaos and finally, complexity will be explained through the pragmatic issues that emerged during the making of Geo_Soft, a rapid prototype sculpture.
Keywords: Complexity Theory, Performativity, Digital Architecture, Representation, Rapid Prototyping, Animation Software, Edge of Chaos.

1 Complexity

Digital Architecture has emerged from technological appropriation and as such has only recently started to develop a plausible theoretical discourse. Unlike most architectural styles at the end of the 20^{th} century that emerged from a theoretical agenda, Digital Architecture has post-rationalised its position in architectural discourse and has attempted to emancipate the discipline of architectural design from a linguistic and representational critique.

Complexity Theory is more then just the opposite of simplicity, it actively seeks to oppose it. Recent architectural design projects generated by exploration

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into advanced 3D animation software have been criticised for being unrealistic, un-constructible and incomprehensible. Part of the criticism aimed at recent digital exploration is that whilst the formal outputs from the computer are radically complex, this complexity is far too easily produced. This complexity appears chaotic and the randomness expresses no apparent purpose, cause or order. This lack of purpose is further used as criticism to define digital architecture as willful and without rigour or intellectual pursuit. However, the chaos inherent in digital architecture is a derivative of its unpredictability, both in its generation during the design process and in its appearance. And yet the forms generated by animation software are graphic constructs of mathematical algorithms which are rational. The apparent randomness of digital formal virtuosity is tied to the parametric and data based inputs that script the formal outcomes. But whilst this scripted, iterative and indexical architecture has the potential to produce a proliferation of formal outcomes, it nonetheless leaves the designer with the difficult role of selecting from a multiplicity of iterative forms.

Complexity can be further explained by illuminating its opposite, namely, simplicity. Simplicity often connotes beauty through the perception of balance and proportion and the cognition of a balanced form and structure that elicits attraction towards objects. This form of beauty, simple beauty, is easily understood by the viewer and allows for the visual consumption of the object without effort on the part of the viewer. Beauty can act in this way: by reducing the complexity of an object into easily definable characteristics, it requires little effort for the object's consumption.

Colin Rowe, in his seminal text 'Mathematics of the Ideal Villa' [3] made connections between the natural beauty of a Palladian villa with idealised beauty of Corbusier's Villa Savoye. Rowe put forward a connection between the two, namely, that both are geometrically derived, offering symmetry and mathematical proportions and are located within an unimpaired natural setting: in other words, order within chaos. But to accept this interpretation of beauty is to accept that architecture is opposed to nature. Humans seek simplicity because it reflects our misguided faith that underlying the nature of our universe is an elegant order. Prior to the digital age, simplicity was desirable as it was easier to calculate without errors. This is no longer the case as computers allow, within a certain range, extreme complexity in the areas of formulation, calculation and construction.

2 From representation to performance

Both Le Corbusier and Venturi sought to represent complexity in architecture as a mechanism to destabilise the status quo of their architectural period. In his 1966 publication "Complexity and Contradiction in Architecture" [1, p.18] Robert Venturi, in a half-veiled criticism of Le Corbusier's 1924 seminal text "Vers Une Architecture", argued that architecture should be "based on the richness and ambiguity of modern experience [due to the reality that] the wants of program, structure, mechanical equipment and expression…are diverse and conflicting in ways previously unimaginable" [2]. Both Venturi and Le

Corbusier separately argued that the “the medium of architecture must be re-examined…” [1, p.18], however, whereas Le Corbusier argued for the programme of a building to be represented using abstract Plutonic forms, Venturi argued for the programme to be represented by “the variety inherent in the ambiguity of visual perception…”. Venturi’s arguments resided in Linguistic Complexity and are aimed at a richness of meaning in a multiplicity of signs, a semiotic architecture aligned with visual arts and literary critiques of the milieu of Postmodernism. Both Venturi and Le Corbusier have viewed architecture’s role as a mode of representation, where a critique of architecture was aimed at satisfying a subjective interpretation of the building. Both also saw architecture as being ‘viewed’ and in this sense consumed. Whereas Le Corbusier sought to simplify the meaning of the programme by enclosing complex programmes in Plutonic solids, Venturi emphasised the complexity of inhabitation by displacing its cultural symbols to the façade. Venturi further postulated an argument that modern architectural projects required a multiplicity of symbols to absorb complexity and to create a rich multiplicity of meanings. His thesis insisted that architecture be critical by creating a set of visual clues that were understandable by society at large. This process of decoding the clues would then simultaneously function as a critique of high art. This reaction to Modernism connected Venturi to Pop Art rather than high art. Although these theories are still current in western architectural theory, the unfortunate architectural outcomes of this type of theory are that, in some instances, they have lead towards a historicist pastiche rather than a critical rethink of culture, history and its society. That is, the reality of society was only ever addressed as a set of images and the critique was representational rather than instrumental, understood only by architects rather than acting upon the intended public audience. Furthermore, this lack of instrumentality has once again lead to ineffectualness and a subsequent demise of historicity in critical architecture.

This is where Performativity has reinvigorated Post Modern thinking and posited the role of signs as active agents of change. As Judith Butler states, the words ‘I now pronounce you man and wife’ [4] changes the status of a couple within a community; those words actively change the existence of that couple by establishing a new marital reality: the words *do* something rather than merely *represent* something. It is in this act of doing that architecture can behave physically rather than just visually. Jesse Reiser [5], writing in 2000, while seeking to break with the semiotic approach argued that architecture should be performative and only secondarily representational. This belief in which Reiser called a ‘complex ecology’, stemmed from his exploration of digital design and bio-technological thinking. Reiser appropriated the concept of the ‘Machinic Phylum’ from French philosopher Gilles Deleuze who perceived life (and therefore architecture) as an overall set of self-organising processes where both organic and non-organic systems connected to create higher level entities. Reiser saw architecture as having reciprocity between its materiality and the human inhabitation: that is, the buildings are asked ‘what they do’ rather than ‘what they mean’. This Performativity of affect can be modeled and tested within the virtual environment of digital space.

3 Performativity

Although it is common to sideline digital architecture to the realm of technology, it has been the power of computer visualisation and the complexity of its formal language that has arguably surpassed previous architectural discourses. By creating a new genre of architecture that could not have been previously possible but for the use of new digital apparatuses, digital architects have re-initiated a debate regarding curvilinearity, expressionism and role of technology in society. In this respect, it is an area of design that is leading exploration into new forms of non-standard architecture. One of the most distinguishing and important features manifested in digital architecture is its performance-based essence.

Figure 1: Geo_Soft, frame 231 from animation sequence.

Notwithstanding the relatively recent expansion in the use of digital technology in architectural practice, it is important to understand that digital architecture cannot be thought of as merely the new era of architecture that came straight after Post-Modernism (as Post-Modernism was commonly referred to as the movement that took place after Modernism). There is much evidence of digital architecture having connections to most periods of the 20th century, including the much criticised and seemingly outmoded Modernism. Support of this statement can be found in some of the recent works of well-known digital architects including Zaha Hadid and UN Studio that are situated closer to Modernism insofar as their adherence to abstraction, geometry, formalism, structuralism and diagrammatic functionalism is concerned. And yet, this new form of modernism is not without meaning or history. Both Hadid's and van Berkel's work have similarities with late Italian Futurists and German

Expressionism of the 1930s. Whilst some may view the connection of digital architecture with Modernism as disturbing (disturbing, because the author agrees with part of the critique leveled at modernism (and the return to it by digital architects) by the writers of the late 20th century including recent connections with Christopher Alexander's matrices, Utopianism, Form follows diagrams (function) to name a few), it only highlights the importance of reviewing digital architecture in a non-linear history rather then labeling it as an architecture that emerged after Post-Modernism. One of the main reasons digital architecture does not sit comfortably as being just another new movement in architecture is that it has borrowed and re-used ideas and objectives from other disciplines, including mathematics and science and is heavily reliant on the software of the graphic and entertainment industries. The exploration of design and technology by digital architects is paralleled in disciplines such as Information Technology, medical and astrophysical imaging, interaction design and naval and aerospace manufacturing.

4 Geo_Soft – a case study

Technology has underpinned the major shift in recent architectural debates regarding formal aesthetics and making. The ideological shift that has occurred due to the proliferation of digital software and hardware has influenced most areas of architectural education, including communications, construction, building science, design and, more recently, theory. At some stage it will also form part of architectural history. The balance of the paper will focus on the design and development of a sculpture produced for a 3D printed sculpture exhibition. This sculpture, entitled Geo_Soft (see figure 1 above) is demonstrative of how formal complexity can be used in architecture.

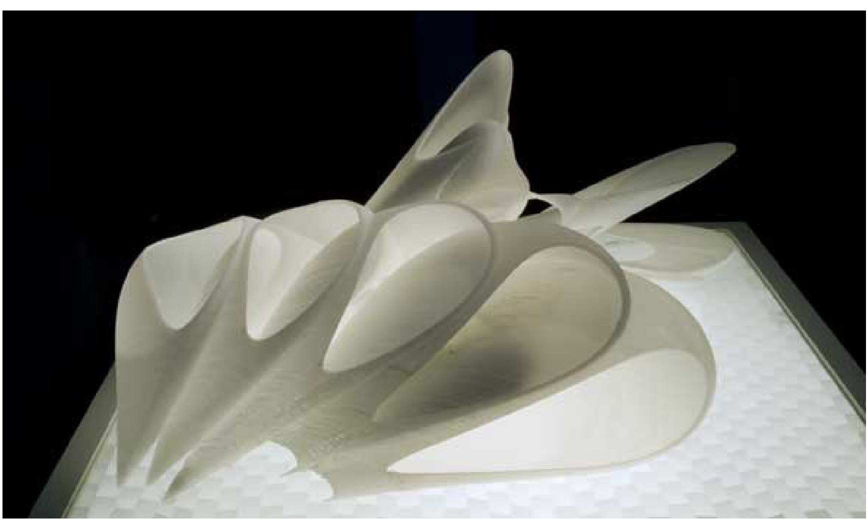

Figure 2: Geo_Soft, Rapid Prototype model.

I was asked by the curators of the madeKnown exhibition to produce a sculpture that could be digitally manufactured using a 3D printer. The design process of the sculpture used digital technologies, including animation software and 3D ABS Rapid Prototypers, to fabricate a complex curvilinear object. The sculpture was conceived during a period of reflection about the theoretical and practical underpinnings of the mDa> lab, the new Master of Digital Architecture programme at the University of Technology, Sydney. Geo_Soft is a printed sculpture that resulted from digital exploration into formal complexity. The complexity of Geo_Soft is paradigmatic of digital technologies and design techniques that (mis)appropriate new media software as generative tools for non-standard architecture. Geo_Soft was conceived as a reconfigurable form that existed both as a conceptual and literal set of ideas. 'Soft' form may connote a malleable artifact that can physically be deformed but this was not the intent of this sculpture. Rather, it was seen as a means to develop a design approach that allowed the process of formation to be adaptive to inputs which would further allow for the absorption of a complex set of informational data and forces into the object. By creating a parametric design process it made possible the resistance to design closure and the maintenance of responsiveness to pragmatic and theoretical design requirements.

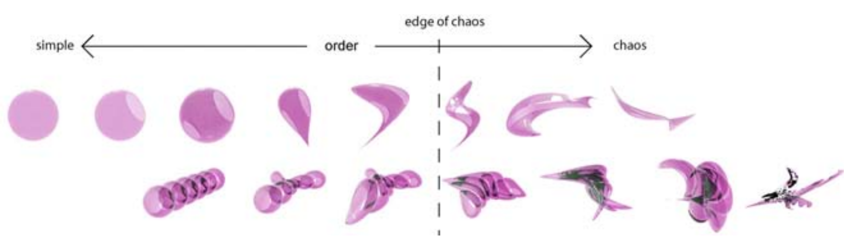

Figure 3: Frames from animation - from simple to chaotic form.

The design process set out to devolve the concept that beauty equates to Plutonic form and statics. This was achieved by starting with a geodesic sphere and deforming its surface's representation by means of mathematically controlled deformers which included twisting, bending and negative squashing by using parametric controlled deformers all within standard animation software. The complexity of Geo_Soft was derived from taking a geosphere and using a diagrammatic technique to develop and embed data-driven distortions into the previously undifferentiated system. However, not only was the sphere deformed, it was also possible to record the deformations over time, thereby creating an animation of the forces that acted on the object (see figure 3 above). This allowed for iteration of the object to be outputted from the animation as each frame of the movie had a distinct configuration. The process produced iterations that increased in formal complexity as the range and amount of inputs increased. Taking this design process to the next level revealed that complexity may be derived from a series of simple subsets or operations that multiply beyond the

Edge of Chaos (the phrase originated from work by the mathematician C.G. Langton in 1990 to describe cellular automata and their ability for a higher level of self-organisation adjacent to a phase-change).

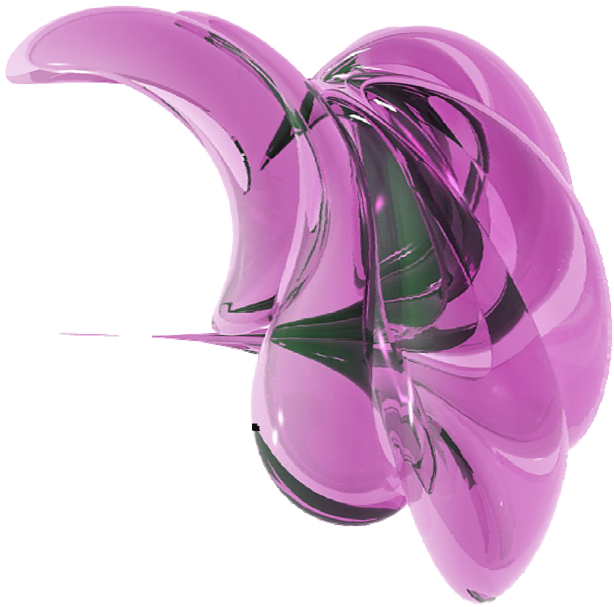

Figure 4: Chaos at Frame 97, darker areas show inverted non-manufacturable surfaces.

A state of chaos had not actually been reached with Geo_Soft: had it done so, it would have resulted in the object possessing inverted curves, lost vertices and multiple Blebs which would have made it un-manufacturable. Therefore, when the topological surface of the sphere curved to overlap itself and thus expose the internal face of the object, a new periodic rhythm and pattern emerged, hence creating an object that was beyond the Edge of Chaos. The first appearance of chaos is found in Geo_soft when its surface imperfects, including the introduction of ruptures, lost vertices or a Bleb. Each of these conditions cannot by printed using conventional 3D printers. The Bleb, as referred to in digital architecture, differs from the common meaning used in medicine for a bulbous protrusion on the surface of the eye filled with fluid. The Bleb has been described by Greg Lynn [6] as the virtual phase change when a deformed geometry is distorted to the point where its internal surface overlaps its external surface, giving the appearance of a bulbous cyst. This underside (inside or non-normal) surface fails to produce surfaces that can be printed. Therefore, by resisting these surface imperfections and maintaining forms at the Edge of Chaos it was possible to seamlessly digitally manufacture this complex form (see figure 4 above).

Building of formal complexity can now be produced by the construction industry as the components are manufacturable ex situ (in factories) rather then the traditional in situ method. If the 20th century is synonymous with the repetitive forms of mass-produced Modernist buildings then the 21st century will see the individuality of mass-customisation. The promise of rapid prototyping machines up-sizing to the scale of architecture no longer appears unbelievable. In the near future, one can foresee entire rooms, houses and even multistorey buildings being manufactured in factories using this method. Current machines can produce translucent and opaque objects that should suit requirements for walls, floors, ceilings, doors and windows. An architect will be able to design and print entire building components and then have them assembled in the factory only to be then transported to site and craned into position. Whilst some of this occurs now with the manufacture of standard components of buildings such as sheds, garages and large multi-storey componentry, what I am referring to is the design of architecturally unique spaces enveloped by 'custom-designed' formally complex shells. CADCAM (computer aided design and manufacturing) is prevalent in most manufacturing industries and will steadily emerge in the construction industry in the coming decades to allow mass-customisation of formally complex architecture.

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Methods for investigating architecture: from the physical to the digital

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Abstract

This paper examines the relationship between traditional and modern methods of architectural investigation, namely: the 'sketch', the 'physical model' and the 'computer'. It aims to test two propositions put forward by two schools of thought regarding the architectural 'method'. The first suggests that the introduction of the computer as a working method would lead to the demise of the more traditional methods of sketching and model making. The second acknowledges the potential of technology but maintains that the computer as a device for abstraction is less effective than traditional systems of representation. A framework, based on the critical review of literature, was established and used as an intellectual vehicle for testing both propositions. It partly revolved around linking Popper's three worlds of knowledge, the subjective, the physical and the objective to the three variables: the sketch, the physical model and the computer. The study concludes that although computers are superior in dealing with complexity, design fixation, and performance analysis of design alternatives, this power does not constitute a sufficient condition, as a cause, for the demise of traditional working methods, as an effect to follow. On the other hand, the biggest strength of traditional methods of sketching and model making is not in the link between drawing and 'visual thinking', as purported by many authors, but it is the material sense of the 'physical' model that gives rise to other senses such as 'touch' and 'physicality'. The missing notion of physicality from both 3D objects and materials generated by the computer is undoubtedly its downfall.
Keywords: the sketch, the physical model, architectural science, the computer, Popper, worlds of knowledge.

1 Introduction

There is growing evidence to suggest that the type of design media one works with will influence the manner in which design problems are explored and consequently determines the nature of architectural product.

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Wienands highlighted the value of ‘languages: words, drawings and models’ architects work with as a vehicle for architectural thought [1, pp. 8–10] suggesting that ‘more differentiated environmental forms are the result of more differentiated thought processes and these require differentiated architectural languages. The more languages or methods used and the more often they are interchanged, the greater the insight gained. The interchange of languages is a methodical help’. A similar view was echoed by Heath who equates the ability of a designer to conceive ideas and produce solutions with the nature and power of conceptual ‘tools’ in her/his disposal [2]. He opined that the limitations of method constrain thinking and will be revealed as limitations of the design. ‘The student who cannot draw freely will design within the limits of his power of representation. He is the victim of analogue take-over’ [2]. However, traditional working methods using models and drawings were pre-eminent during the seventies where little knowledge existed on the use of computers, as ‘symbolic’ models, within the design process. Computers were expensive to acquire and CAAD programmes were not only limited in terms of three dimensional modelling capabilities but also difficult to use. Today it is a different picture as both hardware and software have improved markedly in terms of performance and modelling capabilities. Our knowledge about their integration in the design process has matured and become well established both in education and practice. In fact some of the complexity of the design process can only be dealt with effectively with the use of CAAD in the modelling as well as the manufacturing process of buildings. What is unique about physical models compared to symbolic models of computer and drawings is that notion of the ‘physical state’ which, as a basis for *epistemology*, is deep rooted in the ‘empiricist’ school of thought. Unlike the ‘rationalist’ movement, the empiricists argue that we are born ignorant, we are born without knowledge, and everything we learn is through our senses when they interact with the physical world.

2 The architectural physical model

The use of physical models within design process can serve two purposes: to help designers to ‘explore’ and develop design ideas at a conceptual level and to ‘experiment’ with design ideas, i.e. a vehicle for testing structures, acoustics, etc.

Moholoy-Nagy, an advocate of the use of architectural models in design at the Bauhaus, encouraged students to perform ‘experiment in space’ and create open ‘constructions’ in many materials such as wood, wire, cardboard and perspex so that they may arrive at spatial solutions in three dimensions that satisfy functionally and aesthetically [3]. Knoll and Hechinger classified architectural models into three categories: topographic (site models, landscape models); buildings (urban models, structural models, single building models and interior models); special (design models, object models). These models can be developed in three stages relating to stages of the design process: conceptual, developmental and presentation [4].

The significance of both models and drawings was examined in an exhibition at the Institute of Architecture and Urban Studies, New York in 1976. The aim of the exhibition ‘Idea as Model’ according to Popper was to ‘clarify new means of investigating architecture in three dimensions' and regard models as 'studies of a hypothesis, a problem, or an idea of architecture' [5]. Popper went on to make a significant distinction between modern architecture and the architecture of Beaux-Art in terms of philosophy in relation to their pre-eminent working methods. He draws on Drexler's argument during an exhibition at the Museum of Modern Art the year before. Drexler maintained that modern architecture in its drive towards objectivity relied on the physicality of materials in models as an expression of 'reality' whereas 'the freer, fictive architecture of the Beaux-Arts had depended on the illusions of drawings' [5]. Sharing Drexler's views. Stern argued that the Modern Movement, in an attempt to undermine other types of architecture such as the Beaux-Arts, supported drawing styles which were 'neutral' in comparison to the Beaux-Arts' 'rendered' drawings as well as showing a preference for physical models over drawings [6]. Perhaps the Modern Movement was preoccupied with two notions: how to base architectural knowledge on 'rational' thinking and how to create 'ideas in the objective sense'. Also, the Modern Movement was and is still immensely influenced by Popper's pluralistic philosophy that the world of knowledge, which architecture is part of, is comprised of three ontologically distinct sub-worlds. The first is the physical or the world of physical states or 'visibilia', i.e. materials. The second is the 'mental' or the world of mental states. In architecture this world could be that of design ideas in the architect's mind before they become representations through words, diagrams and sketches. Popper's third world concerns the world of 'intelligibilia', or 'objective ideas'. This world of scientific and mathematical theories is of great importance as it has a great influence on the first world [7]. The world of computers today is part of this world as it based upon artificial intelligence which emanated from scientific and mathematical logic. Computers as a way of thinking have an element of objectivity as they show the designer what is there and allow him to test with confidence his ideas in relation to environmental and structural sciences. The thesis that is emerging in this paper is that somehow, the sketch, the model and the computer each belongs to one of Popper's three worlds of knowledge. The intellectual discourse seems to suggest that the use of computers in design should be encouraged if we were to explore the immense potential of Popper's third world.

Eisenman, citing the role of photographs, argues that the conceptual essence of a 'model' is a 'drawing' and 'a photograph of a building is a narrative record of a fact… the reality of the model because it is the view which reveals its conceptual essence as an axonometric drawing' [5]. Perhaps the role of a photograph is to mediate between a drawing and a model. Yet, Eisenman's view of a photograph being a mere recording device only touches one functional aspect. Other aspects include being a device for demonstration, showing high levels of detail and as a measuring tool, i.e. test structural deflection under different loading conditions.

2.1 The architectural 'science' model

On science models in design, Steven argues that such models are an important vehicle to deal and cope with reality and when models are 'deficient' then we have to accept the lesser learning aid of 'rules of thumb' [8]. He calls on architectural science educators to 'impart even a little theory instead of spoon-feeding students wads of rules of thumb'. His criticism is based on two notions; that rules of thumb provide very little understanding and that they are often contradictory, incomplete and lacking in theory. Models can and have been used to test structural ideas in design. For example Corbusier tested the feasibility of his structural concepts through models. His structural concept for the Philips Pavilion at the Brussels International Fair, a complex hyperbolic paraboloid in pre-stressed concrete, was tested by Bouma through a plaster model to prove its feasibility [9, p. 19]. However, there seems to be claims that the structural concept of hyperbolic parabolic tensile tent came from Xenakis, a Greek architect and music composer who worked in Corbusier's office at the time. Xenakis's complex tensile parabolic form was to be constructed out of lightweight materials. For acoustical reasons the material was changed to pre-stressed concrete to provide acoustical mass for sound insulation. Xenakis's complex parabolic form was generated out of straight lines from pre-cast concrete panels [10]. Gaudi, whose 'poetry of form' gave architecture original thoughts and philosophy on meaning, initiated new methods of structural analysis and calculation using stereoscopic models built with cords and small sacks of pellets to simulate the design of Colonia Guell (1898–1916). A framework of strings was established by hanging them from points representing the specific location of columns in the plan. Sacks filled with pellets and the weight of each sack was scaled down by a factor of 1/10000 – a fraction of what each arch would have to support [11]. This was an interesting moment in the history of architectural technology as Gaudi realised the importance of loading 'similitude' between the model and the prototype. In a seminar on structural model analysis, organised by Princeton University Architecture School, Billington et al. called for a principle of 'similitude'- reduction by a scale factor-to be adopted if model analysis is to have any significance as a design tool for structures [12]. While most students use Billington's principle of 'geometric similitude', they pay little attention to the other two principles: material similitude and loading similitude. The material similitude implies that the modulus of elasticity for both the model and the prototype is the same. Candela, on the other hand, argues against the use of scale models for structural analysis of complex geometry, such as hyperbolic paraboloid, in favour of other method such as mathematical calculations. He maintains that 'some people claim that if the mathematics is too hard, we can always revert to the testing of scale models or photo elasticity' [13]. In such structures, Candela argues, the forces at the edges, which determine the size of edge member, are extremely important and the only way to determine these forces is through calculations. He questions the issue of materials used in models being always different from the real thing. He calls for the use of more precise symbolic models in design. An answer to the questions he raised is through the use of computer modelling of structural behaviour. Not only computer models are quicker in calculations than manual methods, but also they allow the designer to visualise flexes, deformations and stresses within structures which, in the long run, will improve the general understanding of structural behaviour. Citing the experiments of Otto on three dimensional models, Janke views the complexity of interaction between construction and design as a reason for not using conventional calculations on two dimensional sectional diagrams [1, p. 62].

The most common type of architectural science models in design is the light model where scaled physical models provide a relatively accurate simulation of daylight in the prototype. For a complete analysis on the advantages and disadvantages of using physical model to explore daylight see a recent paper by both authors [14]. On the thermal performance of buildings, models can be used for two purposes: the analysis of air movement around building using wind tunnel studies and the assessment of 'skin' changes on indoor temperature. While using models for wind studies is very well known and documented, little is known about using physical models to assess thermal performance. What a scale model offers is the opportunity to test changes in orientation, shading and fabric on indoor temperature under actual climatic conditions.

The viability of using scale models at 1/4 and 1/9 for thermal studies has been investigated by Alexander who concluded: 'the models… appear to provide a useful and practical means of observing the thermal response to climatic variations of different materials and forms of construction. Such observations are of value in assessing the suitability of particular forms of construction for particular climates' [15]. Drysdale built a number of thermal models for houses situated nearby and took measurement of temperature inside the models and the prototypes. He found that both temperatures were comparable. However, he had to make some adjustments to ventilation rates in the models [9, p. 149]. The last discipline in architectural science where models are under utilised is acoustics and in particular sound behaviour in an enclosure. Barron suggested that to 'reproduce an auditorium in a scale model is simpler than many other spaces, because most surfaces are acoustically hard and can be reproduced by hard smooth surfaces, such as varnished timber or plastic materials' [16]. A scale factor of 1:8 or 1:10 was recommended for models to be representative. However he raised many questions regarding the height of labs that can house such large models as well as expenses associated with constructing the models in the first place. Models at scale 1:50 were suggested with a small loss of accuracy.

3 Drawing as an architectural idea

The relationship between architecture and drawing has always been poetic and intense. More importantly, it is the relationship between 'design', regarded as the distilled essence for the discipline of architecture, and the 'sketch', that attracted a great deal of research and scholarship. For instance, Goldschmidt investigates the process of sketching and argued that by sketching the designer does not draw the images he recorded in his mind 'but creates visual displays which help induce images of the entity that is being designed' [17]. Goldschmidt went on to suggest that the 'dialectics of sketching' is the 'oscillation' of 'arguments' between two states until a design solution is reached. If the solution to a design problem is seen as a design 'hypothesis', then sketching can be the process whereby a shift between propositions and counter-propositions occur until a qualitative transformation in the design argument is reached. The type of knowledge used to resolve the conflict could be graphical or non graphical.

Further examination of how much of design can be regarded as sketching is needed. Certain phrases, such as ‘the idea-sketch’ imply that a significant part of design is sketching. Ziesel’s definition of design draws attention to its complexity as an activity as it encompasses three sub activities: imaging, presenting and testing [18]. While the role of sketching in ‘imaging’ is less obvious, its role in judging, testing and refuting design hypothesis at the conceptual design phase and presenting design ideas is there to see. Presumably part of the problem is that at the conceptual design stage the images held in the ‘mind’ and the ‘sketches’ drawn are interchangeable and the continuous feedback which is interactive between the two, is the process at work where the images sketched are judged against those stored in the mind. Yet on further examination of literature the pioneering work of Rudolph Arnheim is very relevant to how ‘sketching’ and ‘imaging’ are related. On drawing as a form of representation, Arnheim’s treatise on ‘Art and Visual Perception’ [19], warns against art being drowned by talk, remarking: ‘visual things cannot be expressed in words’ and ‘verbal analysis will paralyse intuitive creation and comprehension’. In ‘Visual Thinking’ [20, pp. 1–13], he asserts that the separation between seeing/perceiving and thinking/reasoning is unreal and misleading. On the doctrine of ‘imageless thought’, Arnheim seems to argue against the idea that thinking is possible without images, a thought which also came out of Buhler’s experimental studies, [20, p. 101] who maintains that thinking needs a media to happen which could be through words. He goes on to suggest that the imagery can happen below the level of consciousness which cannot be detected by subjects during psychological experiments. To extend the argument further to design, it seems architectural ‘thinking’ cannot happen without ‘imaging’, and ‘sketching’ and imaging are closely related since ‘images’ of an ‘idea’ have to undergo a process of pictorial reasoning through ‘sketching’ before the idea becomes a designed entity (an object) on paper. Other researchers, such as Goldschmidt [21] introduces the dimension of ‘sketching’ as the third dimension in visual perception in addition to Arnheim’s two dimensions of thinking and imaging. Goldschmidt’s famous phrase of ‘figural conceptualisation’ suggests a fusion between two things and a rejection to any dichotomy between ‘concept’ and ‘figure’, i.e. the ‘idea’ and the ‘sketch’. She sees the activities involved in sketching as being: active sketching (hand)→ passive perception (eye)→ active cognition (brain). A further argument against the divide between ‘concept’ and ‘sketch’ is artificial, came from McKim who introduces ‘idea-sketching’ as an evidence for some degree of fusion between figural and mental processes at the early design stage [22]. According to McKim graphic ‘ideation’- the generation of ideas through drawing- occurs through an iterative communication loop where ideas can be added, processed and modified by a collective action by the eye, the brain and the hand through the ‘sketch’. Mezughi [23] identifies two levels of ideation at the conceptual design phase: strategic and tactical. The strategic can be regarded as gestational, aiming to develop visual scenarios and/or images that act like a thesis or anti-thesis before an induced image of the solution is reached and sketched on paper. The tactical level is the 'selection' or 'focus' on one final image or solution.

There seems to be others that place less emphasis on the importance of sketching on the act of visual thinking manifested through seeing and imagining. The implication is the link between sketching and the generation of ideas, is not as strong as previously thought. For example, Levens wrote 'one source of confusion in thinking about design is the tendency to identify design with one of its languages, drawing. This fallacy is similar to the confusion which would result if musical composition were to be identified with the writing of notes… Design like musical composition, is done essentially in the mind and the making of drawings or writing of notes is a recording process' [24]. The limitations of drawing as a recording device were exposed by Lotz who, after investigating the architectural drawings of the Renaissance, concluded that circular interiors could not be drawn 'to provide useful information, such as scaled dimensions' [25]. Moreover, Evans questioned the 'history of architecture' and the special importance it placed on drawing compared to other forms of representation. He raised serious concerns about the 'objectivity' of drawing as an intellectual system of architectural thought. He sought explanations for two intertwined questions: 'how architectural spaces arose out of the deployment of depthless designs, and how architectural space was drawn into depthless designs' [25].

4 The symbolic world of computers: architecture with machines

The computer offers the designer a world of knowledge different from both conventional drawing and the physical model. It is a world based on logic, mathematics, precision and artificial intelligence. When the designer's cognition interacts with the computer a dialogue begins between two systems of thought: the 'artificial' and the 'biological'. It is through this interaction that design cognition- receiving, manipulating and processing information, is bound to experience a change in the way it deals with design problems. This change can take many forms, for instance in designer's creativity domains- ideation fluency and variety [26], in his new attitude toward the design process 'before' and 'after' using the computer [27], in his ability to test design ideas in an objective sense [14]. Above all there would be a change in the designers 'visuality' and the way he sees and perceives images and the way the physical world is experienced through 'simulated' reality.

Review of literature reveals a gulf in opinion on computers and design. Some view the computer as a 'medium' for conceptual design while others regard it as a production 'tool' with little impact on design thinking. The gulf of opinion is not only between theoreticians but also between prominent practitioners. For example in his treatise 'new science=new architecture' Jencks calls for a departure from the old Newtonian linear science to other forms of science such as that of complexity, fractals and non-linear systems. Architecture as 'a form of cultural expression' has to have a similar shift in the framework of thought, he argues. He then cites three 'seminal' buildings of the 1990s to support his thesis of shift. Gehry's Bilbao, Eisenman's Aronoff Centre, Libeskind's Jewish Museum 'are three non-linear buildings and were partly generated by nonlinear methods including computer design', maintains Jencks. He goes on to question the role of metaphor in the three buildings and suggests that 'new science=new language= new metaphor' [28]. Against this is Frampton who advocates a strong link between architecture and building in the 'material' world. Digital design on the computer is a 'fantasy' unless it conforms to 'tectonic', material requirements of the physical world [29]. However, conformity to the 'material' world may inhibit the 'subjective' experimentation of minds in the 'objective' world of computers. A similar conflict on computers and design exists between two world-class architects. Eisenman's writing identifies two intellectual themes about computers and architecture. First, he highlights the challenges to architecture from the 'electronic paradigm' as 'reality' is defined through simulation and 'appearance' is valued over 'existence' [30]. Secondly he acknowledges the creative potential of computers as he asserts that 'the computer gives you the possibility of constructing objects that you would never do directly from the mind to the hand. We constantly produce models after having conceptualised them using the computer, a process of constant refinement' [31]. In contrast, Gehry remains skeptical about the computer's ability to design, stating 'the computer is a tool, not a partner, an instrument for catching the curve, not for inventing it' [32]. However, recent progress in software engineering has furthered the capabilities of some CAAD packages and increased their creative potential as a conceptual tool at an early design stage. In programmes like Rhino, a NURBS modeller, 3D free form organic surfaces and solids can be created intuitively at the early design stage, overcoming serious limitations of traditional polygon software. This appears to address the issue of orthogonal rigidity of the Cartesian system, criticised by Gomez for 'representing another form of modernistic rationality' [33].

Recent work on genetic programming may produce new 'evolutionary' CAD tools that can help designs to evolve from scratch through a process of mutation [34]. Bentley suggests that evolutionary CAD tools, 'allow the designer to explore numerous creative solutions to problems, overcoming design fixation or limitation of conventional wisdom by generating alternative solutions for the designer' [34]. If there is a doubt about the computer as a design medium, it is less of an issue in performance analysis of design alternatives as it is superior to drawings and physical models in terms of accuracy, speed and representation.

5 Conclusions

The study concludes that the sketch, the physical model and the computer all are important methods for investigating architecture and design. Sometimes it is only a matter of difference between designers in their preference for a working method that determines which method they use rather than the objectivity of the method itself in dealing with a particular design problem. Nonetheless the logic of the computer as a mathematical system is by far more powerful than the other

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two methods in dealing with complexity, overcoming design fixation and the objective testing of 'environmental and structural performance' of design ideas. It is also more beneficial for three dimensional visualisation and design cognition. The latter issue which is sometimes called spatial visualisation 'which is the ability to mentally manipulate rotate, twist or invert pictorially presented stimulus objects' that was found to influence academic achievements of engineering students in areas such as structural design, computer aided design and engineering problem solving [35]. However, there exists a lot of misunderstanding in the literature as to what computers can and cannot do. Many scholars suggest theoretical statements about computers without themselves having the necessary skills to operate the computer to its full potential. In some cases they make wrong analogies between the computer and the human mind. For instance 'computers cannot see or dream, nor can they create: computers are language-bound. Similarly, thinkers who cannot escape the structure of language, who are unaware that thinking can occur in ways having little to do with language, are often utilizing only a small part of their brain that is indeed like a computer' [24]. It is fitting to close with a quote from Zaha Hadid who succinctly made an inclusive argument for the three working methods, when she remarked: 'I am sitting there with 15 or 20 computer screens in front of me ... it gives me yet another repertoire. You can see at the same time the section, the plan, and several moving 3D views, and in your mind you can see them in yet a different way. So I'm not sure if it weakens or strengthens your view. I just think it's a different way. We still do physical models and I still do the sketches' [36].

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Global design practice: IT-based collaboration in AEC-projects

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Abstract

Information technology is radically and rapidly transforming the way the AEC industry operates. Large, globally operating firms are often out of necessity on the leading edge of implementing advanced IT-tools because their ability to prosper depends more and more on their ability to use technology to augment industry-wide effectiveness and innovation. To maximize the benefits that lie in company-wide highly integrated information and to foster internal collaboration, such companies often rely heavily on the use of IT supporting their practices. As global projects have become the main sources of revenue for many large AEC firms, geographically distributed project teams and human networks have become more and more common. A wide array of tools is available for IT-based collaboration. Global teams and networks face difficulties that are different from those of teams and networks that are not geographically distributed. These difficulties are usually caused by national, cultural, and organizational differences within the organizations and the multitude of markets they are serving as well as the peculiarities of virtual collaboration. This paper examines these phenomena using the Germany-based Hochtief Group, one of the world's largest AEC companies, as an example. It presents a case study of global virtual teamwork in a recently completed large-scale project in Asia. It then moves on to describe Hochtief's participation in a larger research effort initiated by Stanford University's CIFE (Center for Integrated Facility Management) that examines virtual collaboration in the AEC industry. The results of both the case study and the joint research project are analyzed and presented. They suggest a number of important guidelines for global virtual teamwork in the AEC industry, including the suitability of particular IT-tools as well as the coordination of team members with different national, cultural, and organizational backgrounds over multiple time zones.
Keywords: global teamwork, IT-based collaboration, design collaboration, global design practice, global construction practice, AEC project management.

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1 Introduction

More than anything, a division of labor drives processes in the AEC industry. In the sphere where all areas interface, a large cast of characters – clients, architects, contractors, suppliers and many more – work together as a tight-knit ensemble to meet quality expectations, conclude on schedule, and stay within budget limits. This is why coordination and logistics management are so important. Management is foremost a matter of communication, making the use of sophisticated IT an absolute necessity. This becomes all the more vital as more and more companies have a global presence via subsidiaries and associated companies, and accompany their clients into all regions of the world.

Particularly since the early 1970s internationally offered AEC services increased significantly. In 2000, the revenue of the top 225 international AEC companies was approximately USD 116 billion [1]. Companies from the US and Western Europe were the main actors in these markets. Geographically distributed project teams become more and more common in such companies.

1.1 Hochtief Group

Hochtief Group is a multinational AEC company with partners and subsidiaries in all continents. Founded in 1875, it is currently Germany's largest building services provider. The organization is one of Europe's leading players in the AEC industry. Following the acquisition of Turner in the USA in 1999 and the engagement in Ambro/BFC in Canada, Hochtief has made the step to one of the world's leading construction companies. In 2001, the company had approximately 40,000 employees worldwide. Its total revenue in 2000 was around USD 12 billion, 76 percent of this revenue was generated with global projects [1].

Together with its subsidiaries and associated companies, Hochtief began gearing for a joint IT/Internet project in late 1999. The keywords of this initiative were "transparency, autonomy, and openness" [2]. The companies were focusing on a number of areas specifying development work that needed to be done. Collaboration and project management of geographically distributed project teams was one of the main areas of the efforts. The goal was to give project participants instant access to the same central data. Since collaboration in the AEC industry relies heavily on time- and cost-intensive communication between a host of partners in far-flung locations – via conventional channels such as phones, fax, paper, and mail. In Hochtief's comparison with conventional tools, Internet-based applications came out as the clear winners: particularly in the design phase, a central electronic project file could facilitate the exchange of data. Up-to-the minute information could be available to all parties at all times. Geographical distances would no longer be important because everyone involved could use a standard web browser to access the same project file wherever and whenever necessary. The system's workflow capabilities would ensure documentation of individual process steps and continuous updates on status

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information would allow monitoring and keep projects on track. The 1999 initiative focused on the technical aspects of global collaboration. However, practice showed that the issues of global collaboration were more complex.

1.2 The Taiwan High Speed Rail project

The Taiwan High Speed Rail Project was a typical global AEC project for HOCHTIEF. A high-speed train rail connection of approximately 40 kilometers in length, the project included the building of several bridges as well as a train depot. The project was located in an area with a high earthquake risk. The project team included a British office, several offices in Taiwan and India, a contractor's independent checking engineer in Denmark and numerous other experts and consultants located all over the world [3].

1.2.1 Steering of design and construction

In a project like Taiwan High Speed Rail, the early recognition of problems was crucial. This meant a continuous

- questioning of executed project parts
- discussion of typical problems
- discussion of technical standards
- discussion of local practice
- questioning of appropriateness of software tools
- Exchange of drawing samples to clarify graphic standards

1.2.2 Design quality

Quality requirements had to be checked systematically:

- design quality plan: illustration of the project organization with responsibilities
- design manual: communication with client and subcontractors
- CAD manual: requirements of client
- quality checks: always in house at HOCHTIEF in Germany
- construction requirements: examples for standard details for subcontractors

1.2.3 Document management

Approximately 12,000 drawings were produced over the course of the project. Each drawing had to be revised about 2–3 times which lead to a total number of approximately 30,000 drawings that were sent electronically to project partners and subcontractors in Taiwan, Germany, England, India, Malaysia, and Denmark. All other documents – calculations, meeting minutes, contracts, correspondence, etc. – were handled in the same manner. Project servers were located in Germany, Taiwan, and Denmark. The servers were synchronized several times during each day so that all project participants had the same information status at all times.

In summary, the Taiwan High Speed Rail Project showed many characteristics of global AEC projects:

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- project teams geographically distributed
- different time zones
- different cultures and languages
- IT-based communication
- different national standards

The wish to better understand the peculiarities of such a highly IT-based collaboration led HOCHTIEF to the participation of Stanford University's Global Teamwork Project in 2001.

2 Global Teamwork project

The master builder's atelier in the information age was the vision behind an integrated research and curriculum in AEC Global Teamwork offered by the Department of Civil and Environmental Engineering at Stanford University in 2001 [4]. The project examined the use of modern communication technologies to promote better collaboration in projects where team members are geographically separated from one another. The objectives of Global Teamwork project were to develop, test, deploy, and assess new Workspaces and IT processes, including learning, work culture, and new approaches to multidisciplinary collaborative, geographically distributed teamwork

The goal was also to educate students as the next generation of design and building professionals to know how to team up with professional from other disciplines using IT and to leverage collaboration and IT to improve processes as well as products.

The core of the project was the "AEC Team": students who played the role of the apprentice, AEC graduate students and who played the role of the journeyman, faculty members and researchers who played the role of the "master builders", and industry members who played the role of mentors, owners, and sponsors. The project engaged 43 students from 10 universities worldwide (20 from Stanford and 23 from other university partners) in twelve AEC teams – USA: Stanford, UC Berkeley, Kansas University, Georgia Tech; Europe: TU Delft (The Netherlands), ETH Zurich and FH Aargau (Switzerland), Bauhaus University (Germany), Ljubljana University (Slovenia) and Stanford Japan Center. The participants were challenged to cross four chasms:

- AEC cross-disciplinary project-based teamwork
- use of information and collaboration technology
- team coordination over multiple time zones
- team coordination over multiple cultures

Each team was geographically distributed over two or three time zones. The Stanford lab computational infrastructure offered the necessary spectrum of information and collaboration technologies, such as video-conferencing, video-streaming, web-based collaboration applications team discussion forum, 4D-CAD, project group spaces, Internet 2, wireless and mobile infrastructure.

The project started in January 2001 with a kick-off event that brought together all the students, faculty, owners, and mentors at Stanford University.

During that time students engaged in team building exercises, met their "owners" and were introduced to the project and basic collaboration technologies. After the kick-off all students went back to their campuses and for five months learned and worked in cyberspace. A halfway milestone was the concept development presentation event that took place in cyberspace via video-conferencing and application sharing. Students, faculty and mentors experienced presentations and discussions of projects in a global environment. Some industry members connected to this event from their trailers on a construction site. The project culminated in a final team project presentation in May when all students, faculty, owners, and mentors came to Stanford again to share their products, processes, experiences, lessons learned. The Global Teamwork project showed remarkable parallels to the demands placed on construction teams in the framework of large-scale global projects in the AEC industry as described in the example of the Taiwan High Speed Rail project.

2.1 Experiences with the Global Teamwork project

After the end of the Global Teamwork project, Hochtief invited all participants to a workshop at its headquarters in Essen, Germany, to discuss the experiences gathered in the project and to identify improvement potentials for collaboration in global project teams. The following is a summary of the main issues that were raised by the participants:

2.1.1 Time for technical issues

A wide range of tools were available for the communication in meetings and events of the Global Teamwork Project. Especially audio and NetMeeting turned out to be problematic. Dealing with technical problems required 50–60% of the team meeting time in the beginning of the project. This percentage was lowered to 10–20% as the project proceeded. The real problem turned out to be the poor audio connections that significantly affected the quality of the communication in the meetings.

2.1.2 Time for communications tools

The geographically distributed teams relied on IT communication. Clarification of project issues using NetMeeting required approximately 30–40% more time as if the team members would have sat together physically.

2.1.3 Getting familiar with software

Many project participants had to learn new software. Requirements were the creation of a homepage, 3D and 4D models, and PowerPoint presentations. The communication tools, FTP, AutoCAD, MS Office, etc. were required as a standard. Depending on the individual experience of the participants it took up to several weeks until everyone handled the software efficiently.

2.1.4 Suitability of IT tools

Since the project had about 40 participants, technical requirements had to be clarified in advance. The following tools were the standard to guarantee collaboration:

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- MS Office 2000
- Frontpage 2000
- AutoCAD 2000, including ADT (Architectural Desktop)
- 3D Studio Max
- Adobe Photoshop
- Video conference system
- FTP
- Internet access
- ISDN for audio conferences
- Specific versions of Internet Explorer
- Specific versions of NetMeeting
- Software of the several project disciplines (cost estimation, etc.)
- Common data storage

2.1.5 Teams

Personnel requirements turned out to be at as least as important as technical requirements. Crucial were:

- reliability
- communication skills
- fluent project language (English)
- impartiality
- openness
- pro-activeness
- motivation and commitment

It turned out to be beneficial to allow the establishment of personal contacts before the start of the actual project. It paid off to have common relaxing activities as well as playful tests of collaboration. It became clear that it took time to bridge differences of language, culture and personalities. It also became clear that the better the initial phase of personal meetings was, the better the actual project collaboration was.

Team members had to be clear from the very beginning that they had to share all relevant data with their colleagues. It was important that the members explained each other what their work, their goals, their thoughts, and their proposed solutions were. Interaction only took place when members understood the concerns and ways of thinking of the other disciplines. The skills of forming a good team required the willingness to interact with each other already in the conceptual phase of the project.

One of the most important issues of the project was the organization of teamwork. It was important for the teams had to have a project manager. Project documentation had to be detailed and always up to date. A project homepage proved to be a good tool.

Bringing together the various disciplines already during the conceptual design phase turned out to be essential. The requirements of the various disciplines then had an impact on the project from the very beginning. This improved the quality of the team. Each team member stood behind the project with discipline and motivation. Generating requirement lists of the single disciplines proved especially helpful. These were lists of things one would like, common to-do lists, etc.

Information exchange had to be carefully organized. On one hand this was a technological problem: how and in what time intervals the information exchange occurred, how and in what software version information was stored etc. On the other hand this was a content problem: what kind of information was necessary at what time and what kind of decision had to be made by the whole team and what not. What had to be handled in a synchronous manner and what could be handled in an asynchronous manner?

It turned out to be important to develop a common structure for all participants in the beginning of the project. Competences and responsibilities had to be clarified but still be kept flexible to a certain degree. Team processes like communication, flow of information, design, etc. had to be carefully organized and structured. Different time zones turned out to be difficult for scheduling meetings for all participants.

3 Conclusions

During and after the workshop at Hochtief's headquarters in Essen, Germany, the Global Teamwork participants discussed which were the most important lessons learned for global IT-based collaboration. The following is a summary of what the participants felt were the most crucial issues.

3.1 Communication

Communication happened on the level of relevant information as well as on the level of emotional relationships between the team members. Any kind of information exchange caused emotional reactions and influenced the quality of collaboration. The project showed that the spatial distribution of the team members reinforced these effects. The project participants agreed that it is an essential advantage for a geographically distributed team to have an initial phase during that it was possible to physically meet. The geographical distribution of the members had to be compensated with more intense communication using the many different IT tools.

3.2 Trust

Because of the geographical distribution and the resulting anonymity within the teams the development of trust through openness, helpfulness, and tolerance seemed even more essential for the success of the projects.

3.3 Structure of teams

Having a team leader and inventing rules for collaboration turned out to be even more important as if the team would have worked together in the same location.

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3.4 Structure of tasks

The same was felt for the structure of tasks: clearly and early articulated time frames, goals, milestones, distinction of responsibilities, and level of processing turned out to be especially helpful.

3.5 Excellent technical equipment

The elixir of life in the project was intense communication. If this was not guaranteed, frustration and disintegration occurred within the teams. IT therefore had to be excellent in the sense of being reliable.

3.6 Goal-oriented information management

The answer to the following question turned out to be essential for the success of the projects: which kind of information should be transmitted when and in what depth through whom to whom? It was an ideal situation when each member of the team had the same information status at all times.

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[3] In February 1999, Hochtief also founded a technical office in India that offers services for all divisions of the company. Since then, the staff has grown significantly. Services range from the creation of reinforcement drawings all the way to quantity surveys for major construction projects. They also provide support in material procurement. Depending on the location of the project, the team in India provides German, British, US, or Australian standards.

[4] The project, headed by Prof. Renate Fruchter, was part of a continuous research program of Stanford University's Department of Civil and Environmental Engineering that was established in 1993.

Acquisition of designable space for planar steel frames

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Abstract

This paper describes a methodology for the acquisition of designable space for planar steel frames. Here, the designable space is obtained out of the universe which contains the all sets applied for a structural design of a building. A designer takes some sets of solutions simultaneously using a new concept design system, although he or she gets only one set of solutions with the conventional method. The new concept design system was developed taking the knowledge system and data flow system into account.

For a convenient structural design system for unskilled engineers and students, a new concept needs to be introduced to the conventional structural design system. It is a laborious process for beginners to become skilled in structural design because it often takes a long time to find the rational solutions to design problems.

The new concept for a structural design system is developed with Excel and DSP. Excel is used for the development because it is the most popular spreadsheet type application and uses the programming language VBA. DSP is the special computer language which is developed by Nagasawa and possesses a high potential for writing design codes. This system has the capability to get designable solutions simultaneously. This is proof of the new concept as an acquisition of designable space. A demonstration was conducted as to how a designable space moves in the whole design space.

Keywords: structural design, computer assisted design, design space.

1 Introduction

This paper describes on both a concept of acquisition of designable space and a methodology for the acquisition of a pertinent solution for planer steel frames. A

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structural design system of arbitrary shape steel planar frame based on a knowledge system was developed in this study. The system is different from other conventional structural design systems in the concept and the architecture of processing. Conventional structural design systems often force the beginner into a laborious process of finding the rational or best solution. Consequently it is difficult to become proficient with these systems in a short time, although the systems are used as effective tools by structural design experts. This study is aimed at developing a system that advances structural design skills for structural design beginners. There are various knowledge-based expert systems for structural design [1], although they are not suitable for the beginners.

2 Designable space and pertinent solution

2.1 Acquisition of design solution

An action of the structural design is to select a unique rational or reasonable data set (called a *pertinent solution* in this study) applied for the structural design of a building from all designable data sets (called a *design space* in this study). However, there is a lot of designable data sets in the design space. It is inefficient to calculate all sets at one time, because it would take too long to achieve. Therefore, some design solutions (called *designable space* in this study) under constrained conditions are acquired from the design space and a pertinent solution is acquired by moving the designable space into the design space [2]. In the study, a pertinent solution is distinguished from the optimal solution. A pertinent solution is selected by the designer's decision, although the optimal solution can be calculated automatically.

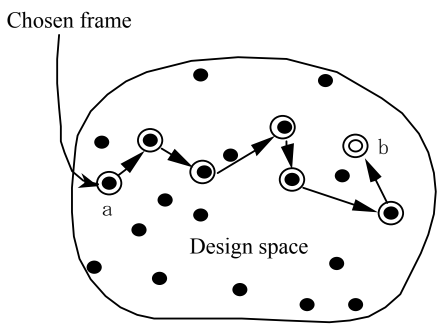

Figure 1: Pertinent solution search in a conventional structural design system.

2.2 A comparison of the new concept with the conventional method

A model depicting the pertinent solution search in a conventional structural design system is shown in Figure 1. In the pertinent solution search in a conventional structural design system, a designer takes the first prepared frame (a, in Figure 1) and examines the frame for structural design using the result given by the system. When the designer is satisfied with the frame the design process is finished at this step. If not, designer has to select other frame from the design space and examines it. In this way, he or she implements a pertinent solution search from doing a rundown.

On the other hand, there is a model depicting a pertinent solution search described 2.1 and shown in Figure 2. In this process, a designer takes the first prepared frame (a, in Figure 2) in the same way as in Figure 1 and he or she acquires some designable frames (designable space) constituted by members that have a close dimension to that of the member that constitutes the assumed frame at a time. When the designer reasons that the point marked b is the best frame fulfilled design condition, the design process is finished at this step. If not, the designer makes point b the new assumed frame and implements an acquisition of new designable space. At this time, if the designer reasons that point c is the best frame fulfilled design condition, this design process is finished. However, if this is not the case, the designer repeats the previous step with the same methodology and acquires a pertinent solution (d, in Figure2).

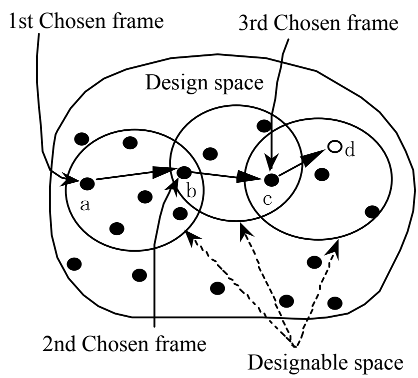

Figure 2: Pertinent solution search in the new structural design system.

3 New concept design system

3.1 Development of a new concept steel structural design system

A new concept structural design system, that is achieved by the design process concept as described in Chapter 2, for steel planar frames was developed in this study. The system is applied to arbitrary shape steel planar frames. The system was developed with Excel and DSP. Excel is the most popular spreadsheet type system, which uses the Visual Basic for Applications (VBA) programming language, and is able to handle figure or graphics on the sheet. It is convenient for dealing with arbitrary shape frame design. On the other hand, DSP is a special computer language that was developed by Nagasawa and possesses a high potential for scripting design codes and also has a generate-and-test method function [3]. These are the reasons why Excel is used for the development.

Structural member design in a steel frame is based on the specification for steel structure design in Japan [4]. The expression of equations and notations described in the specification generally has the form shown in Figure 3. However, if those in Figure 3 are coded in the conventional computer language such as Basic or Fortran, the description sequence of program code must be deferent from the sequence shown in Figure 3. Also, a large amount of labor to develop whole system is necessary for systems programmed in Basic or Fortran.

$$\frac{\sigma_c}{f_c} + \frac{{}_c\sigma_b}{f_b} \le 1 \qquad (6.1)$$

and

$$\frac{{}_t\sigma_b - \sigma_c}{f_t} \le 1 \qquad (6.2)$$

where

$$\sigma_c = N/A$$

$${}_c\sigma_b = M/Z_c$$

$${}_t\sigma_b = M/Z_t$$

Figure 3: Expression of equations and notations in design specification.

On the other hand, DSP is a spreadsheet type application and it uses the concept of data flow. This means a programmer doesn't have to take care of the sequence of program code. Therefore, not only a usual computer programmer but also a designer, who is not familiar with program coding, can develop a system by themselves, and he or she can rapidly respond to changes to the design specification.

4 Outline of the system

4.1 Graphical user interface of arbitrary shape steel planar frame

It is necessary that there is a graphical user interface (GUI) for a system user to design an arbitrary shape steel planar frame for visualization. In the study, Excel is used for the GUI of the system. It is the reason why Excel is taken for the development is that it is the most popular spreadsheet type application and uses the VBA programming language. Also, it can handle graphics on the sheet. It sets some buttons and menus to be able to implement the selection and change for input and output by the mouse. An outline of an arbitrary shape frame is drawn at upper left of Figure 4, and information of structural members and load conditions is also included. A demonstration of the methodology for acquisition of pertinent solution is shown in Figures 5 and 6.

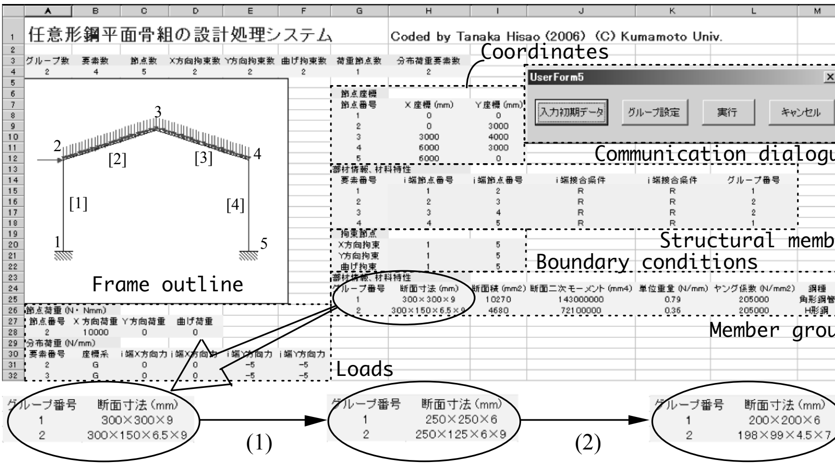

Figure 4: View of spreadsheet and process of change of members.

An example process of the methodology is described below. One set of structural members such as beams and columns of which the frame consists is prepared for the first structural analysis and examination of all the members. From this the first acquisition of designable space is achieved, as shown in Figure 5. The vertical axis in this graph is the total weight of the frame, which is designable, and the lateral axis is member height, which is variable for the design. Constrained conditions are shown in (1) of Table1. The first chosen member for examination is plotted as a point (a) in Figure 5. A change of members for the improvement of the design solution is implemented by clicking on another design solution in this designable space. For example, when the lightest frame (b) in Figure 5 is selected, the previous data of each member in the frame is replaced by new value. As a result, all members are refreshed on the data input sheet, shown in Figure 4.

When the designer needs another improved solution, the rewritten members are applied for the next structural analysis and those are examined with the structural design code. Also the designer takes new constrained conditions shown in (2) of Table 1 for getting lighter designable members. As a result, the designer gets the new designable space shown in Figure 6. When Figure 5 is compared to Figure 6, it is shown that the designable space moved in the design space. More rational reasonable solution for him or her is acquired by selecting a design solution (c) which is the minimum lightweight data set in designable space shown in Figure 6.

This agrees with the process shown in Figure 2, where the pertinent solution is acquired by moving the designable space in design space.

Table 1: Constrained condition for acquisition of designable space.

	Item	Colum (Square steel tube)	Beam (H-section)
(1)	Height	350 - 250 mm	350 - 250 mm
	Width		200 - 100 mm
(2)	Height	250 - 0 mm	250 - 0 mm
	Width		150 - 0 mm

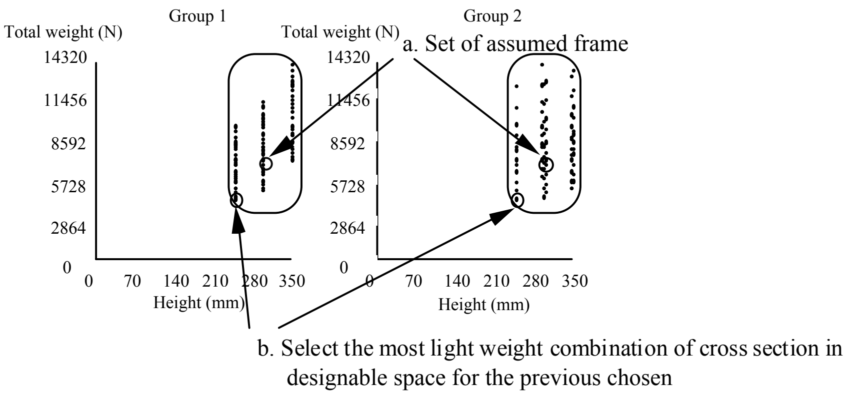

Figure 5: Acquisition of designable space (1).

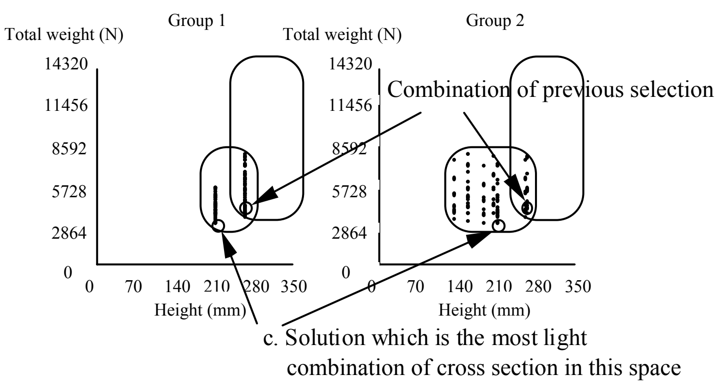

Figure 6: Acquisition of designable space (2).

4.2 Constitution of the system

The structure of the system is shown in Figure 7. In the system, the selection or consideration of design solutions are implemented by human decision for a human-driven design style, although calculation is implemented by computing system. The visualization of the designable space is a noteworthy aspect of the system that makes comparing data of members easier for designers.

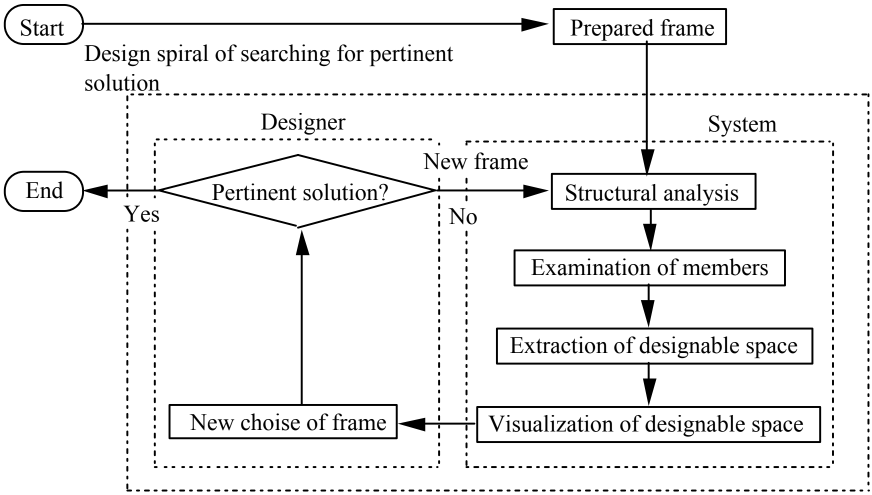

Figure 7: Design procedure of structural design system for arbitrary shape steel planar frame.

5 Conclusions

In this paper, the visualization of designable space in the structural design system for arbitrary shape steel planar frames based on a knowledge system was introduced. This system with new concept means that the unskilled structural designer can easily obtain the pertinent solution out of many designable data. This is a proof of the new concepts capability for the acquisition of designable space. A demonstration was outlined for how a designable space moves in the whole design space.

Acknowledgement

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The study of design problem in design thinking

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Abstract

The view of design as a kind of problem-solving activity has been an important base in the study of design cognition. Most of time, the researchers identify design problems as design briefs. But recently, some results of protocol analysis have implicated that design problems are not only about the briefs and need not exist at the beginning of design. This paper studied the roles of design problems in design thinking by protocol analysis. The results show that there are two kinds of problems which occur in the design process: one is related to the brief, and the other is about designer's intention. The advanced study has been focused on the differences of the thinking mechanisms of these two kinds of problem.
Keywords: design problem, design thinking, design cognition, protocol analysis.

1 Introduction

For a long time, design has been regarded as a kind of problem-solving activity. From the early researches on design methods and methodologies to the lateral design cognition studies, this viewpoint has been the common base. What is more, design problem is defined as the brief of design, which is usually induced to the functional requirements. However, some results of protocol analyses have showed that design problems are not only about the briefs and need not to exist at the beginning of design. These phenomena indicate that the contents and meanings of design problems in real design are different from what the problem-solving theory has claimed. The former is some kind of fact from thinking report, and the later is determined by definition. Not from a prescriptive consideration but a phenomenon study, this paper aims to clarify the differences so as to investigate the thinking characteristics of design problems.

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2 Design problems in problem-solving theory

Many researchers have pointed to the properties that separate simple and well-defined problems from complex and ill-defined ones. Both Reitman [6] and Simon [7] discuss the nature of ill-defined problems in detail. But the criteria Simon suggests for well-structured problems are still vague. And Akin [1] considered the properties of design what constitutes the "ill-defined". When they discuss the definitions or structures of design problems, they describe the incompleteness of requirements of client, from which the ill definition of problem space is deduced.

The typical point of view regards design problems as design briefs and has spurred many researchers on to study the functional problems, which are always the major topic in design briefs. These efforts focused on improvement of design methods and reasoning in dealing with complex briefs, such as the research of architecture planning. And Alexander's research (1962) is another kind. He combined the functional and formal facets of design to decompose a huge and complicated structure – an Indian village into some hierarchical small units. He tried to advance design problem solving by decomposing a big problem into some sub-problems. These researches look for to overcome the ambiguity of design problems specified in design briefs.

Some characteristics of design problems in problem-solving theory can be collected as follows:

1. Design problems are regarded as the content of client briefs, which describe the goal of design, and especially as functional requirements.
2. The informational completeness is major concern for problem space definition. This incompleteness makes most of real world problems to belong to ill-structured problems.
3. The position that the problem-solving theory considers problems is for artificial intelligence, but not necessary for human designers. And most of the definitions or criteria are established for the convenient to the computational ability of a problem-solving system, which is always referred to computers but not human beings. It is a kind of prescriptive discussion on problems in the theory of problem solving.

3 Research issues

These prescriptive notions of design problems have led the developments of artificial intelligence, but also result in some lost when they are extended to represent characteristics of human thinking. From some design protocols recorded in the precedent research (Chiang and Wang, [2]), when designers reported their problems in design processes, they talked about some contents, which really baffled them, different from the briefs. So what is the nature of these differences? Does it mean any different meaning of thinking? To answer these questions it needs to study design problems from human thinking.

In order to improve the understanding the characteristics of design problems in design thinking, the close studies of real-word design process could offer several critical discoveries. Lawson (Lawson [5]) points out some important characteristics of design problems after many observations of designers at work. He mentions that design problems cannot be comprehensively stated, require subjective interpretation, and tend to be organized hierarchically. Comparatively speaking, Lawson concerns more about the actual way in which designers think, and has observed the impossibility of complete and static formulation of design problems. Although Lawson points out subjectivity in interpretation of design problems, he seems to restrict such subjectivity only coming from domain disciplines.

This paper emphasizes that another more critical factor of subjectivity interpretations on design problem results from designers' intentions, especially in high creative design. This paper differentiates designers' intentions from various design disciplines and methods, and identifies such intentions as a key factor to make design as art. The actual contents of designers' intentions could contain life values, design philosophies, particular preferences and so on, which are usually formed not in particular design courses but as an integrated effect of various experiences and learning. This factor is usually disregarded in the so-call design professional studies, but keeps conducting design implicitly. In design competitions, designers can make various interpretations, and so can form many different design solutions for a common brief. It seems unsatisfactory to explain the variety of competitive solutions induced only from similar professional disciplines. This paper argues that it is designers' intentions that make similar disciplines generate different solutions. And all of these results begin from problem interpretations by designers' intentions, which phenomena could be observed only in empirical studies of design thinking, and is easily ignored in normative discipline studies of design. This paper considers that if design problems are not equal to design briefs, what do they mean in design thinking? And if designers' intentions influence the recognition of real design problems, how do they perform in design?

4 Two types of protocol analyses

In the experiments, the aim is to study the differences of designers' cognitions on different definition-degree assignments with individual briefs, which were so called the documents specifying design problems. In the traditional preposition of design problem as design brief, better-defined problems could be expressed as a set of better-defined briefs and so do worse-defined problems. In order to find out the key characteristics of design problem cognition, this research compared design processes of different defined briefs. From the best-defined brief to the worst one, five degrees are classified. This research took design experiments on first four better-defined briefs. This set of experimental designs proceeded in a closed-experimental environment. Another well-defined aspect of experiment is about the design environment. Each design experiment is restricted at one room and during a regulated short period of time.

Comparatively, The worst-defined brief is represented as a real-world design program and has proceeded in an entirely open environment as real world. The aim of real-world design protocol is used to investigate the designers' cognitions in open environments and through longer periods. The former well-defined environment controlled designers to design effectively and mostly by knowledge and heuristics. But the later real world as an ill-defined environment, opening these controls to designers themselves, allows something different and uncontrolled to happen. By comparing the cognition of design problems in different-defined design assignments and environments, the common characteristics could be found out. This paper analyzed these two kinds of design protocols individually and comparatively.

4.1 Experiments on different definition-degree briefs

4.1.1 Experiments

The experiment is composed by four sub-experiments, each with individual design assignment. From better-defined briefs to the worse-defined one, four experimental assignments are "geometry arrangement", "furniture arrangement", "space design", and "architecture design". The subjects were three master-degree architects. They were experimented separately. Table 1 shows the working frame of experiments. These three subjects were asked to draw their designs on the papers and report their design processes as well as their concurrent thinking immediately after the individual sub-experiment. All the verbal reports were translated into scripts. Each statement was numbered as "X-Y", where "X" is the number of sub-experiment, and "Y" is the order number of the statement in the protocol. The three subjects were coded as "A", "B", and "C".

Table 1: The frame of experiments.

Sub-experiments	Assignments	Degrees	Periods
1. geometry arrangement	Given a set of geometries, arrange them into a given space.	Best-defined	20 min.
2. furniture arrangement	Given a building structure, functional requirements and a set of furniture, arrange furniture into the structure.	Well-defined	20 min.
3. space design	Given a building structure and functional requirements, design the interior spaces.	Ill-defined	20 min.
4. architecture design	Given a site and functional requirements, design the architecture.	Worst-defined	30 min.

4.1.2 Results and findings

Following are results of experimental protocols.

1. In the geometry and furniture arrangement sub-experiments, all three subjects reported what problems they encountered in design processes. The reports of problems occurred not at the beginning but only after a period of design development. For examples:

(C: 1-01) At beginning, I put the pieces by size. The bigger should be placed earlier. And then I felt that there was something wrong.

(C: 1-06) I began to try from the middle-size piece. But there was a problem of corner.
(A: 2-05) The kitchen puzzled me most, because there was almost no space left for it.
(B: 2-22) Especially the location of the toilet door, it was the first problem I dealt with. I like it not easy to be seen but easy to use.
(C: 2-21) At last, the problem was about the unarranged furniture around the central area. I don't know how to locate them.

2. In the space and architecture design sub-experiments, all three subjects didn't report any statement as problem. But, all of them reported their "wishes", which never occurred in the first two other sub-experiments. These "wishes" sometimes are as clear as a request in (C: 3-31), and sometimes are vague without real contents, such as (B: 3-23) and (B: 4-33). For example:

(A: 3-10) But I wish the space be more fluid.
(B: 3-23) I wish this space (entrance) be special.
(C: 3-31) I wish there will be a window to see the garden.
(B: 4-33) Because it is a literati space, I wish it offered as a special space in architecture.

By analyzing the content of problems, reported as above, there are two findings:

3. The problems, what subjects reported, are not the only content about the requirements, what briefs ask for, but always some "dissatisfactory relations" between requirements and spatial forms. This dissatisfaction seems to be the major factor of problem recognition, and consists in two or more aspects of spatial properties, such as functions, locations, dimensions, views, circumstance, and so on.
4. There are different criteria of evaluation of design: one comes from the requirements, and the other from the subjects' wishes. This finding seems that the evaluative criteria can distinguish the dissatisfactions, so designers could recognize them as problems.

4.2 Real-world architectural design protocols

In the study of real-world design practices, which face the open defined problems and are in open environment, the main goals are to reveal the critical thinking characteristics of design problems by which designers were baffled in the extreme. This research has interviewed four real-world designs, in which all of designers once encountered big bottlenecks and finally break through them. Two of these four proceeded in architecture design courses, and the others in architecture practices, one is on design commission and the other is for design competition. These designers separately presented their sketches, design drawings and models and reported their concurrent thinking and doing after a period of time when design has been finished. Compared to think-aloud or retrospection protocols in experiments, there may be some information missed or forgotten in these protocols, but what were remembered must be important and considered well enough for designer to store in memory so as to retrieve. Since this type of protocol can filter off the trivial treatments in temporal thinking and leave the influential thinking in memory, it deserves deep study.

4.2.1 Analyses

This research coded the whole design protocol into several sequential sections according to the history of designers' reports. Each section is numbered as "1", "2", "3"… according to its order. By overall review of each protocol, there are eight factor categories defined to encode the attribution of each statement. These eight factors are classified into three types of divisions: "design premise" as the beginning causes of design, "design thinking" as the thinking body of design, and "the exterritorials" (Ex) containing all information and events outside the territoriality of the preceding design thinking but jumped into design occasionally. In premise division, there are three factors including "design requirements" (abbreviated as "Rq"), "design constraints" (Cs), and "designer intentions" (DI), which are frequently reported. According to the findings of above experimental design protocols, since designers' wishes play an important criterion role as design requirements in the cognition of design problems, it should be the same as requirements in the premise division of whole design thinking. In thinking division, there are four factors including "design problems" (P), "design orientations (Or), "design operations" (Op), and "performance evaluations" (E). These four categories classify the content types of thought described in statements.

By the above encoding system, each statement could be noted by its category abbreviation and sequential number. For example, "P1" represents the statement describing particular design problems in design section 1. There are two purposes of the analysis: one is to find out the factors influencing design problems mostly by the analysis of relation-equations, and the other is to understand the composition of design problem by analyzing its content. For the first purpose, the research analyzed the relationships of design problems with other factors and notes them as relation-equations. For example, "P1=DI1+Rq1.2" means that P1 is related to DI1 and Rq1.2.

For the second purpose, the research designed another notation system to formulate the dissatisfactory relations in design problems, which is revealed in the analyses of experimental design protocols and mentioned in 4.1.2. In the statements designers reported, design problems are always about that something of design were unknown, conflicted with each other, or in bad situation. These "something of design" means the elements of a design problem. And all the unknown, conflict, and bad situation mean various dissatisfactory conditions. In this part of analysis, the contents of design problems are further decomposed into three types of elements, which are "form aspect" representing formal attribution of design contents, "meaning aspect" representing all other attributions of design contents excluding form, and "design operation aspect" representing the information about how to design. The dissatisfactory conditions are judged by the value of element sets. Each type of problem elements has its own criteria, which are guided by the briefs or designers intentions and noted as "F" for form aspect, "M" for meaning aspect, and "O" for design operation aspect. If the element set of actual situation is unsatisfied, the research defines that its value is lower than the criterions. For example, “image”<F+M” means that the problem element “image” is unsatisfied in its form and meaning aspects. The coding results of design problems in these two systems are shown in Table 2.

Table 2: The analyses of design problems in real-world architectural design protocols.

Designers	Problem statements	Relation-equations	Composition analyses
I	1. This project was named ‘N. Y., N. Y.’ The client wanted the building with the image of the Liberty, but I really cannot design such.	**P1=DI1+Rq1.2**	‘image’ <F+M ‘cannot design such’ <O/?
	3. He still wished the image of the Liberty, but we didn’t like to design in post-modern way…	**P3=DI3+Rq1.2**	‘the Liberty’ <F+M post-modern way <O/?
	4. After that, we considered a simpler way to attain the effect he wanted…	**P4=DI4+Rq1.2**	‘a simpler way’ <O/? ‘the effect he wanted’ <F+M
	5. We reverse this proposal by ourselves. We returned to think how to make the form simpler.	**P5=P4=DI4+Rq1.2**	‘how’ <O/? ‘make the form simpler’ <F
	7. then I thought of how a glass curtain-wall can be designed to express the image.	**P7=Or6+Rq1.2**	‘a glass curtain-wall’ <O/? ‘to express the image’ <F+M
II	1.This was a difficult project because of the lack of site characteristics. It was an underground station design. You can have any expression only in a few constructions sticking out the ground.	**P1=Rq1+Cs1+DI1**	‘lack of site characteristics’ <M/? ‘have any expression’ <F
	2. For a period, I looked for how to do it?	**P2=P1+DI2**	‘how’ <O ‘it’ <F/?
	3. It is easy if just to make a form. But this form will have no any spirit. I don’t know why I do it.	**P3= DI3.1+DI2+Op2+Ex2.1**	‘make a form’ <F ‘any spirit’、’ why I do it’ <M/?
	4. What feel should they evoke? What image should these constructions express?	**P4= DI3.1+DI2+DI3.3**	‘feel’, ‘image’ <M/? ‘constructions’ <F
	7. One night, I thought that what this form could be represented as, if the design concept is “urban festival”.	**P7= Op6.1+Op6.3+DI3.3**	‘what’, ‘urban festival’ <M/? ‘this form’ <F ‘represented as’ <O

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Table 2: Continued.

III	1.1 I wanted to talk about American culture and Chinese culture by design. 1.2 …so by the difference of these two cultures, containing the varieties of the traditional and the modern. 1.3 …and there is a changing from a super culture to a sub-culture when it migrated. 1.4 …so I had been thinking that how to design an architecture expressive of these conflictions of eastern/western cultures, tradition/modernity, and super/sub-cultures.	**P1.1= Cs1+ DI1** **P1.2< P1.1** **P1.3< P1.1** **P1.4= P1.1+P1.2+P1.3**	'culture' ⊲M 'the traditional and the modern' ⊲M 'a super culture to a sub-culture' ⊲M 'how to design an architecture' ⊲O+F/? expressive of these conflictions ⊲M
	3.What can represent the culture?	**P3<P1.4**	'what' ⊲F/? 'represent' ⊲O 'culture' ⊲M
	4. The most difficulty is how to express a modern temple in a complex district, because the traditional from of temple is too strong. How to transform it?	**P4=DI4.2+DI4.1**	'express', 'How to transform' ⊲O/? 'a modern temple' ⊲M+ F
	5. It still failed to evoke an association with a temple, although it was transformed from traditional spatial sequence and characteristics.	**P5=P4+Op4+DI5**	'evoke an association' ⊲M 'from', 'spatial sequence and characteristics' ⊲F/? 'transformed' ⊲O/?
	7. I stared to consider the way of transformation of this fixed form.	**P7<P5**	'transformation' ⊲O/? 'this fixed form' ⊲F
	8.But it was still difficult. So I still had no idea about how to do it.	**P8=P7+Or7**	'how to do it' ⊲O+ F/?
IV	6. It seemed to need some transformations of elements.	**P6**	'transformations' ⊲O/? 'elements' ⊲F
	9.Here occurred a biggest problem. …it was the plan of the four classrooms…at beginning, the stairs was placed here for the convenience, but it became obstacle.	**P9=Op8.2+DI9**	'the stairs' ⊲F/? 'the convenience', 'obstacle' ⊲M
	13. …then why should be it? After lots of tries and errors, why I still insisted on it?	**P13=DI10+E12.1**	'it (the stairs)' ⊲F 'why' ⊲M/?
	14. …but had no idea about how to do them (stairs and obstacles)?	**P14=P9=Op8.2+DI9**	'how' ⊲O/? 'stairs' ⊲F 'obstacles' ⊲M/?

4.2.2 Results and findings

1. Two important findings are shown in Table 1 too. One is that all problems consist in two or more types of elements. The other is that there is always an element unknown or unsatisfied, which is noted as "?" in Table 3 in design problem. These phenomena together reveal the recognition of design problem as an unknown or unsatisfied situation within restrictions conducted by designers as well as clients.
2. A summary of the analysis of the amount of occurrences of factors in relation-equations is shown in Figure 1. DI is almost the most frequent influential factor in each protocol, even in the protocol-I, it appeared only one less time than Rq. The result indicates that DI plays a dominant role in the formation of design problem.
3. The main design problems in these real-world protocols all are dominated by designers' intentions. In protocol-I, the designer preferred the simple and abstract form, which was conflicted to client's request of post-modern image. In protocol-II, the designer looked for the proper spirit of form. In protocol-III, the designer searched for the effect method of transformation of traditional temple with its spirit. And in the protocol-IV, the designer struggled with the big problem resulted from his aesthetic preference and insistence on a particular staircase in his preliminary design.

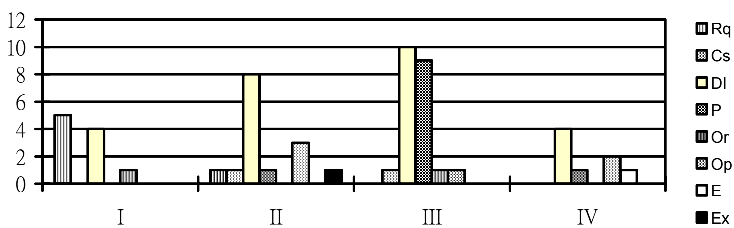

Figure 1: Analysis of appearance times of factors.

4.3 Comparative analyses

When a designer deals with these different-degree-defined briefs, is there any different or common recognition characteristic on design problem? What are they? These two questions conducted the comparative analyses of protocols. The comparative analysis of two kinds of design protocols is shown in Table 3. There are several interesting findings in the cross comparative analysis, shown as follows:

1. Designers didn't reported any design problems in protocol (3) and (4). It seems that design problem needn't occur in designers' thinking actually, even though he is doing design. Will the kind of design thinking this phenomenon indicate be the same to problem solving? It is still a question, which need more investigation.
2. What designers recognize as a design problem is not equal to design brief, since in experimental assignments, like protocol (3) and (4),

worse-defined briefs didn't result in more problems than better-defined briefs.

3. The occurrence of designers' intention coincided with the ill-defined assignments. Only when the assignment is open enough, design intention could get a chance to "emerge". There are two reasons this research calls its appearance as "an emerging". One reason is that the intention is always either unclear or unmentioned at beginning, but becomes more and more clear along design process. The other is that the designers' intention is flexible and could be adjusted to different design environments. When the environment, containing its briefs and physical environment, is ill defined, the intention usually dominates the formation of design problem. But when the environment is well defined and restricted, the intention either is not proposed or offers an effective guidance to design development, where it creates particular characters but no problem.

Table 3: Analysis of results of different definition-degree protocols.

Types of design protocols	Definition-degree of environment	Definition-degree of assignment	Designers' intention description	Design problem description	Related factor of problem
(1) Geometry arrangement	+	++	×	○	Brief
(2) Furniture arrangement	+	+	×	○	Brief
(3) Space design	+	−	○	×	×
(4) Architecture design	+	− −	○	×	×
(5) Real-world design	−	− − −	○	○	Intention

5 Conclusions and suggestions

By analyzing design protocols with different definition-degree assignments in different definition-degree environments, this research has revealed some characteristics of design problem in design cognition, which are different from what problem-solving theory suggests. Design problem always relates two or more of three aspects: form of production, meaning of form, and operation of design, and occurs in designers' cognition when these aspects are in some unsatisfied situations. It seems that there are concealed criterion behind the judgment of "unsatisfied": one is from design brief as those problem-solving theory discussed, the other is due to designers' intention. In the latter, a designer is not just an entity, which can use knowledge and heuristics to design, but also a self-devoted worker. The work of clarifying these differences in design problem aims not at any meaning of definition but at revealing the important thinking phenomenon about design problem, which may have evoked a particular thinking mechanism and need to be more considerations for understanding human design cognition.

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PerFORMance: integrating structural feedback into design processes for complex form-active surfaces

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Abstract

This paper outlines a method of using Finite Element Analysis (FEA) software to study the behavior of materials, geometries, and configurations to create an iterative design feedback loop for generating and refining complex configurations of form-active surfaces. The method integrates technical feedback on structural performance – material stresses, deformations and elastic buckling potential – while respecting design intention and promoting constructability, improved structural performance, and syntactic consistency. Instead of the 2-dimensional (planar) technology which drove modernist analysis towards the structural hyper-rationality of the trabeated system, this new process compiles and synthesizes computational speed, mathematic principles, mechanical knowledge, and material logics within a digital 3-dimensional (spatial) analytical environment in order to realize a new paradigm of constructible complex surface structures. The research focuses on the development of structural performance criteria for form-active structures and interoperability techniques/protocols between advanced CAD systems and advanced structural analysis systems in order to create a fluid design + analysis process of generating and engineering complex form-active designs.
Keywords: FEA, structural analysis, structural surface, shape stiffening, buckling, computation.

1 Introduction

Today the architectural discipline finds itself having mastered the representational production of blobs, folds, cells, webs, cracks, crystals, fractures, plumes, drips, nests, sponges, shells, et cetera. The explosion of

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formal possibilities created by intuitive geometric modeling environments have lead architects to design many freeform complex surface geometries without concern for constructability or structural feasibility. Now architects are left asking themselves the age-old question: how do we build these forms? This question leads us to the next question: how do we analyze these forms structurally in order to predict how complex surface geometry will actually behave in the physical world? Thus far we have usually seen a material-spatial schism at this point in the design process into a fairly normalized stick frame structural system clad with a complex skin.

This schism is caused in large part by our inability to integrate the structural analysis of complex surface forms into a fluid design process based on a design + analysis feedback loop allowing for structural feasibility and improved system performance that is fully representative of geometry and materiality. This is one of the primary problems in realizing these complex forms in the physical world while maintaining conceptual consistency. However, the technology to analyze these forms mathematically is quite mature and is ready for architectural appropriation. Finite Element Analysis (FEA) is an analytic method for calculating the structural behavior of objects, and is the method by which designers can now work iteratively between formal desires and physical behaviors. By utilizing FEA designers can begin to move towards a more holistic design process where architecture and engineering are collapsed into a singular hybrid.

The problem is rooted in an architectural design philosophy that is hylomorphic in nature. Manuel DeLanda describes this hylomorphic paradigm as “a view of matter as an inert receptacle for forms imposed from the outside” [1]. Designers project their formal desires and intuitions onto materials and generate geometries without regard for the physical behaviors produced by those decisions. This is why most formally complex designs must be ‘simplified’ and ‘normalized’ within engineering conventions so that we can predict behavior and protect the public health, safety, and welfare. When built, these designs are normally split into a two-part system of structure and surface, often having little rational relationship between the two systems. If designers had the ability to analyze the structural behavior of their formal creations continuously *during* the design process, would this information impact formal decision-making? We argue here that the feedback derived from the analysis of material properties and geometric behavior using FEA can and should affect formal decisions in order to create a new paradigm in which complex structural-surfaces are realizable as self-supporting constructions, also potentially capable of carrying significant external loads. Additionally, analytical structural feedback should be used as a design generator, or collaborative partner, for the creation and articulation of geometric and spatial complexity through intricately articulated form-active surfaces.

Although much more automated, stochastic, and discrete, similar conceptual ideas of incorporating structural feedback into the formal creation process can be found in the work of Kristina Shea’s Eifform Software. Eifform is a rule-based formal generation package that incorporates structural behavior into a generative algorithm to produce iterative, optimized design solutions based on predetermined performance criteria. This approach considers structural behavior as equal to formal manifestation. The algorithm uses shape instantiation and a process of structural optimization based on crystallization called simulated annealing to create designs that produce 'structural efficiency, economy of materials, member uniformity, and even aesthetics' [2]. While not directly related to FEA the parallels between the work presented here and the Eifform strategy are clear.

2 Finite Element Analysis

Finite Element Analysis (from here forth referred to as FEA) is a mathematical method for analyzing the behavior of form and matter based on an approximate discretized representation of a desired condition with topologically connected 1D, 2D, and 3D Finite Elements. This method was developed for the aerospace industry in the 1950s to replace the traditional method of 2D/3D truss analysis and to reduce the need for empirical testing through full-scale mockups. Because the existing method of analysis assumed limited types of behavior it worked well for simple trusses and frames. However, it was not suitable for complex forms because of the unpredictable nature of complex shapes. The advent of digital computing made the difficulty of analyzing complex 3D shapes possible through FEA. The Boeing Corporation was the first to successfully analyze a complex surface with an early version of FEA in the 1950s [3].

Finite Element Modeling is structured into a three-part environment of pre-processor, solver, and post-processor. Pre-processors are used for generating the FE mesh from CAD geometry and setting up the necessary conditions for completing the analysis. Once the model has been completed in the pre-processor, a FE input deck is normally written out to a text file and submitted to the solver where the mathematical abstraction is assembled and the model is solved. The solver then writes a results file that can be viewed in the post-processing environment [4].

Depending on the nature of the analysis, the results could include the deformations of the structure under loading, the stress state of the materials in the structure, the buckling factors (eigenvalues) and buckled mode shapes (eigenvectors) and vibration frequencies and mode shapes (another form of eigenvalues and eigenvectors). A linear-elastic FEA is most commonly used and cannot assess whether the structure is damaged due to yield/fracture of the materials or whether the structure has undergone wholesale geometric changes due to excessive deformation. A non-linear FEA can model complex behavior such as crushing and post-buckling, but such behaviors are rarely permissible in architectural structures – so such non-linear analyses are rarely used. The most "accessible" forms of structural feedback are the stresses, which indicate whether the materials are performing within safe limits. Deformations are also easy to understand, with designers being able to use intuitive judgment to assess whether the movements of the structure under various loads are acceptable. Buckling and vibration are complex structural phenomena – but must be considered if thin-skinned complex membrane forms are to be considered.

One of the most important aspects of this process is the fluid translation of information from the design environment (CAD) to the analytical environment (FEA) and back again. This translation is critical to the usefulness of FEA as an iterative design tool. In the past, FE models where built manually in a pre-processor environment or in a text editor. This was a time consuming, tedious, and error prone process. Every node (point where the continuum is broken into discreet parts) had to be manually input through coordinate definition and then elements created through nodal connectivity. One can easily see why complex forms would not be easily analyzed in this type of constructive environment. However, today algorithms have been created to automatically generate FE models from well-formed CAD geometry, opening the door for designers to analyze complex forms quickly and with less specialized knowledge.

The key to making this process successful from a CAD perspective is to have well-formed, clean geometry that does not contain anomalous conditions. In addition to geometric fitness, CAD files should be well organized into layering schema that will aid in the meshing process down stream. In single body models this is less of a concern, but in multi-body models containing connections this can be the difference between hours and days of pre-processor work. In multi-body, connected models, all points of connection should be geometrically identified and organized into discrete layers in the CAD model. This will greatly simplify modeling connectors in the pre-processor. Lastly, geometric aides can be modeled in CAD to aid in a variety of pre-processor tasks. For example, lines can be created to establish vectors where loads will be generated in the pre-processor. In general, it is advantageous to create as much geometric and spatial information within the CAD environment as possible because pre-processors are still quite clumsy in comparison. Once the geometric model is complete it should be exported to a neutral file format that is supported by the pre-processor such as IGES, DXF, or ACIS.

After CAD geometry has been imported into the pre-processor the model should then be organized into component layers, material properties, and Boundary Conditions. Once the basic organizational schema has been built meshing can begin.

Automeshing techniques have been one of the key factors in making FEA a viable design tool. Automeshing is the procedure by which raw surface or solid geometry is translated into a variety of different 2D shell/plate elements or 3D solid elements. The resolution of the discretization process is controlled by the designer, but the software calculates the three-dimensional coordinates of the nodes and keeps track of element connectivity. This mesh is analogous to a tessellated surface mesh in a CAD environment. The elements can be of either first order or second order type, each containing up to 20 independent nodes. Second order elements generally give better results but are more computationally expensive. Automeshing maps FE elements to geometry and creates a single collector (layer) that is organized into geometry and elements. The retention of this relationship between the element and its originating geometry is critical for a variety of reasons including the ability to refine the mesh of elements after geometric manipulation and for mapping connectors, constraints, and loads.

Automeshing often needs to be refined in order to obtain high quality results for final engineering checks. However, for initial design analysis most automeshing algorithms yield acceptable results. The exercise in Section 4 will only deal with the meshing of 2D shell elements, which are analogous to thin surface structures.

Once meshing is complete, property attributes for elements and materials should be defined. For 2D shell elements the most important property to define is the virtual thickness. The thickness is considered virtual because the thickness is constant within the formulation of the element and does not need to be modeled in CAD. In addition, most solvers require the user to give instructions on how to deal with elements as either shells (2D) or solids (3D). Material properties must then be defined and mapped to the proper elements. Most linear static FE analyses define materials as being homogeneous and isotropic. Other material properties such as Modulus of Elasticity and Poisson's Ratio must also be defined [5]. These material properties are easily accessible in a variety of engineering references for common structural materials.

The final step in setting up the model in the pre-processor is the creation of Boundary Conditions, from here on referred to as BCs. BCs are locations where loads (forces) and fixed points (constraints) are defined within the model. Loads can consist of many different types of forces; points loads, pressures, accelerations, moments, etc, and are all applied directly to individual elements or nodes. The study below will focus on uniform loads of a constant magnitude. This loading schema will be representative of gravity loads. Constraint points describe how the model is fixed in space. The structural solution will provide a force (or moment) reaction at each point fixity. In three-dimensional models, every point (node) has six degrees of freedom (DOF), three translational and three rotational. For every constraint, each of the six DOF can be independently defined. Models which are inadequately constrained are unstable, that is, when the forces are applied to them, they move as a rigid body instead of deforming and remaining in one place.

Once the model has been constrained and a variety of forces have been applied, Load Steps, or Load Combinations, are created. Load Steps allow for multiple loading permutations to be solved for a single structural construct.

The model is now ready to be solved. An FE input deck is written out from the pre-processor and then submitted to the solver for analysis. Once the analysis is complete, the solver will output a results file based on the results that were requested from within the pre-processor. This results file is then read into the post-processor for visualization and results analysis [6].

The results obtained in the post-processor from the results file become the structural feedback data that designers can use to modify and develop geometric conditions based on performance and design intensions. The format of the result is critical for designers to be able to intuitively react to the analysis. Rather than outputting hundreds of pages of nodal displacements as text, contemporary post-processors can generate sophisticated plots, graphs, spreadsheets, and animated simulations of shape behavior along with many other forms of user-friendly representation.

3 Structural criteria for form-active surfaces

FEA is capable of analyzing many different types of scenarios and behaviors including temperature gradients, acceleration, vibration, etc. In order for the process of design, analysis, and feedback to be productive, set criteria must be established for the architect to react against. These criteria should be intuitively comprehensible and must also be highly generative. In other words, the resultant data must be useful for the architect in making decisions about which formal operations to use where, and why those operations are useful. The two primary feedback criteria to be used in this process are material stresses and buckling. Material stresses and buckling modes will be analyzed using gravity-loaded shell structures to predict behavior and search for design opportunities. These design opportunities are defined as moments identified through FEA where shape-stiffening formal manipulations will contribute to the geometric realization and overall structural performance of the project.

Analysis of material stresses are important in order to ensure that the limit state of the material is not exceeded so that rigidity is retained. A safety factor of one-half the material limit state is typically used in designing for stresses. For ductile materials such as steel, the limit state is usually defined by the yield point. FEA calculates stresses in the geometry and displays the results as easily read colored contour plots in order to consider the effects of stresses on materials and in making dimensional decisions.

Buckling is the phenomena where an object with internal compressive stresses gives way and drastically changes its shape. It is caused by an instability in the structure. Buckling phenomena can be explained and predicted by using stress values to formulate an eigenproblem. Eigenproblems yield eigenvalues and eigenvectors. The eigenvalues are the load multipliers that describe the load level at which the structure buckles, along with the original loading pattern. The eigenvectors give the pattern of displacement of the structure as it buckles. The eigenvectors are only a visual pattern of the displacement – the magnitude of this pattern cannot be determined and it is generally considered to be infinite – that is, the onset of buckling is a catastrophic failure of the structure. FEA will produce both colored contour plots and simulated animations in order to visualize buckling behavior along with determining the BLF (Buckling Load Factor) The BLF is the multiplier of the applied load at which the structure will begin to buckle.

Once the FE mesh has been loaded and an analysis has been run the results of the analysis can be read by the designer as feedback for modifications and development. Areas of large deformation would require the most shape-stiffening operations and therefore would present design opportunities manifest as shape-stiffening operations. These operations can come in the form of folds, bulges, knots, and many other techniques that increase the amount of 3D shape in the project geometry. This is where design intension and designer's intuition come into play. The objective of this process is not to *optimize* the shape solely based on structural performance, but rather to create an iterative dialog between designer's intuitions/desires and structural behavior.

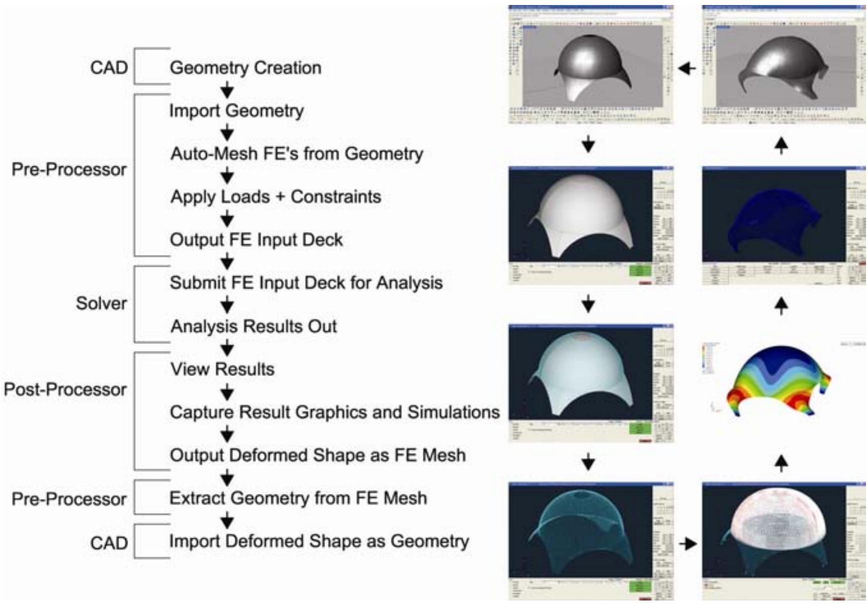

Figure 1: Process of translation from CAD to FEA.

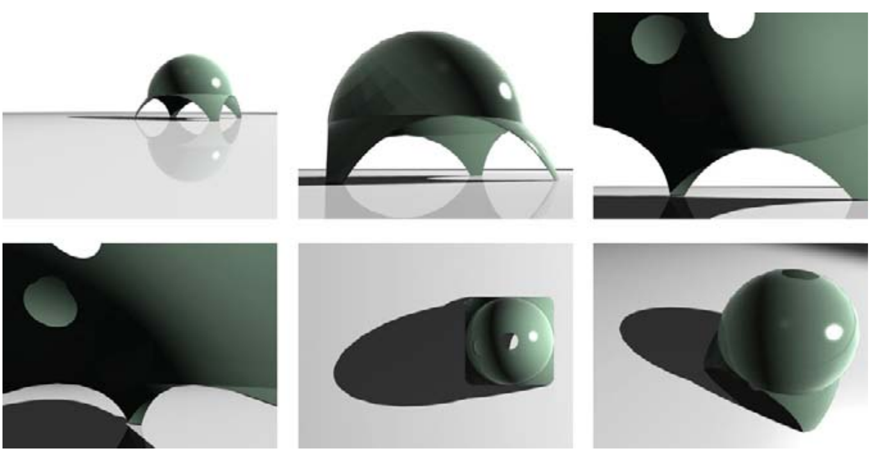

Figure 2: Original dome geometry.

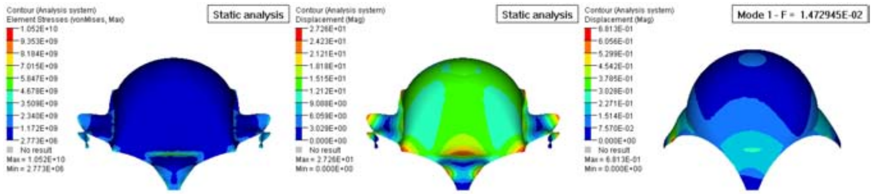

Figure 3: Analytical results for dome.

4 Design experiment: folding the dome

The following design experiment tests the premise of using FEA as structural feedback in the iterative design of a self-supporting structural skin. Starting with a semi-spherical dome, the experiment is set up as a prototypical transformation of an archetypical form. The original dome has a span of 43 m, as taken from the dimensions of the Pantheon in Rome, and is set on top of four pendentive arches. The thickness of the surface is 0.00635 m (6.35 mm) and is modeled with the properties of mild steel. After the CAD model was converted to a FE mesh, the FE model was loaded with a total uniform load of 5.3×10^6 N, which is the equivalent to the load that would be produced by taking the area of the structure's footprint and loading it with a generically derived load of 60 lbs/ft^2. This loading is arbitrary as the project has neither program nor specific occupancy, and is the combination of a 40-lb/ft^2 live load and a 20-lb/ft^2 dead load.

The base of each pendentive was then continuously fixed at every FE node and given zero DOF. An analysis was then run on the dome for buckling, stress, and displacement. The results of this analysis were captured, considered, and then used in the transformation of the dome.

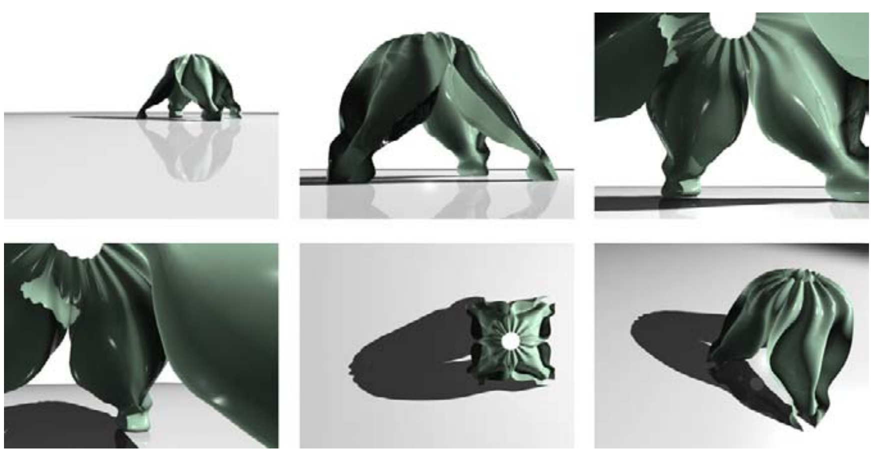

Figure 4: First iteration dome transformation.

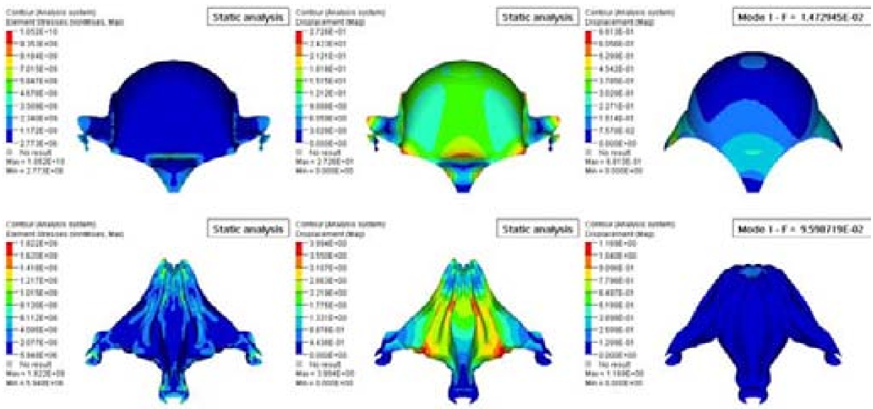

Figure 5: Comparison of analysis between original and first transformation.

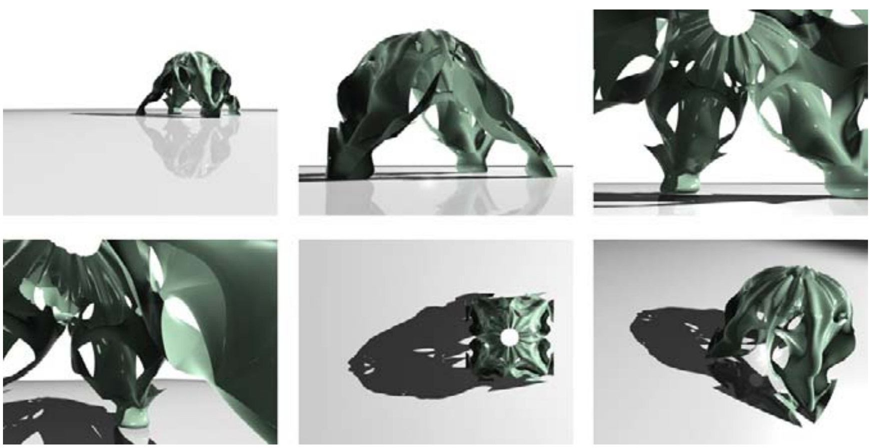

Figure 6: Second iteration dome transformation.

Each transformational iteration tries to introduce shape-stiffening operations in areas of high deformation. Geometric complexity and surface continuity are gradually produced as overall stiffness is increased.

Decision making for which formal operations would be used to modify the initial geometry came from a mixture of designer's intensions/intuitions and analytical results from the FE dome model. Analysis of the original geometry shows buckling behavior in the pendentive legs that identified an opportunity for shape-stiffening operations. Additionally, the upper portion of the dome was shown to be performing quite well with the original geometry. Therefore a strategy of lofting from deep curves in the lower regions to shallow curves in the upper region was implemented.

The original geometry was first superimposed with the deformed geometries from the buckling analyses to give a spatial frame of reference to the designer. This is of course an exaggerated representation, however it is an intuitive context for spatial thinkers. The shapes were then deconstructed and used to generate deep sinuous curves that were then lofted to produce the four folded legs in the next formal iteration. The curves were drawn perpendicular to the line of intersection produced by slicing a plane through the dome on a 45° diagonal in plan. In other words, deep curves were drawn perpendicular to the original dome and then swept, using lofts, 1-rail sweeps, 2-rail sweeps, and surface blends. The material thickness remained constant throughout all iterations, more or less maintaining an equivalent usage of material.

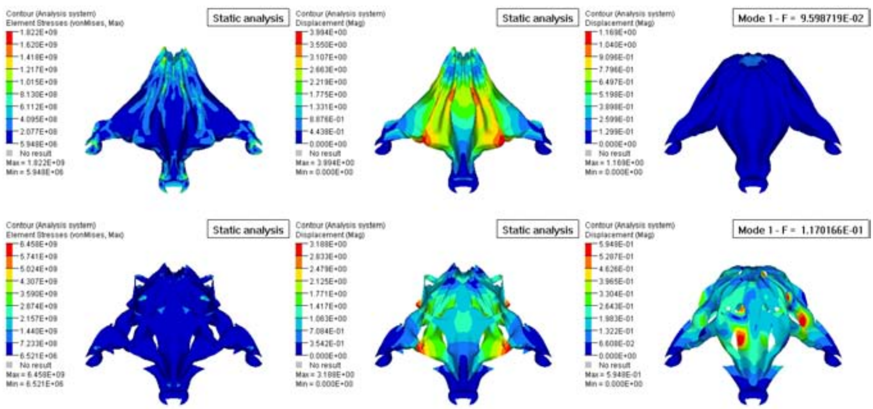

Figure 7: Comparison of analysis between first and second transformation.

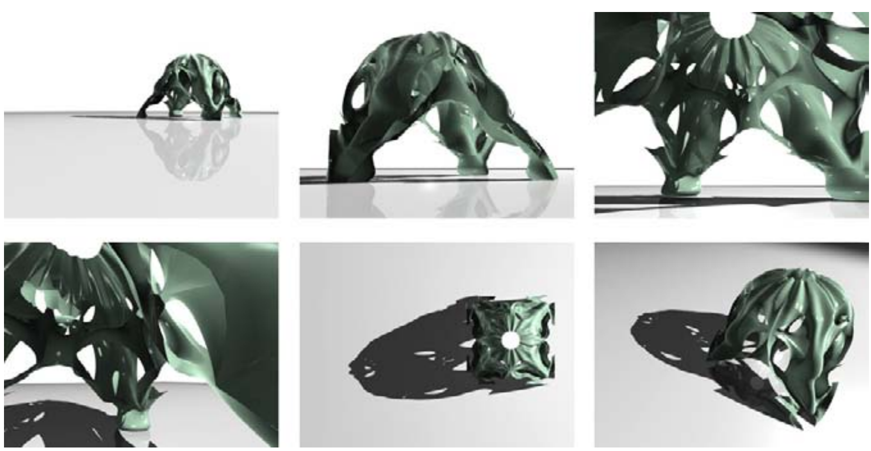

Figure 8: Third iteration dome transformation.

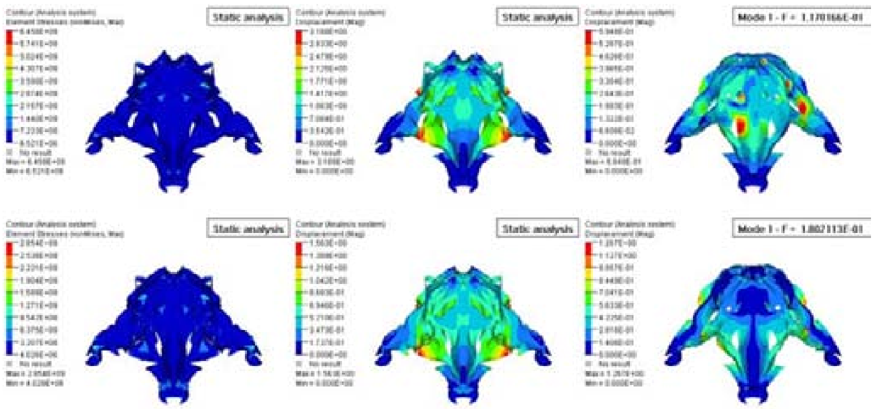

Figure 9: Comparison of analysis between second and third transformation.

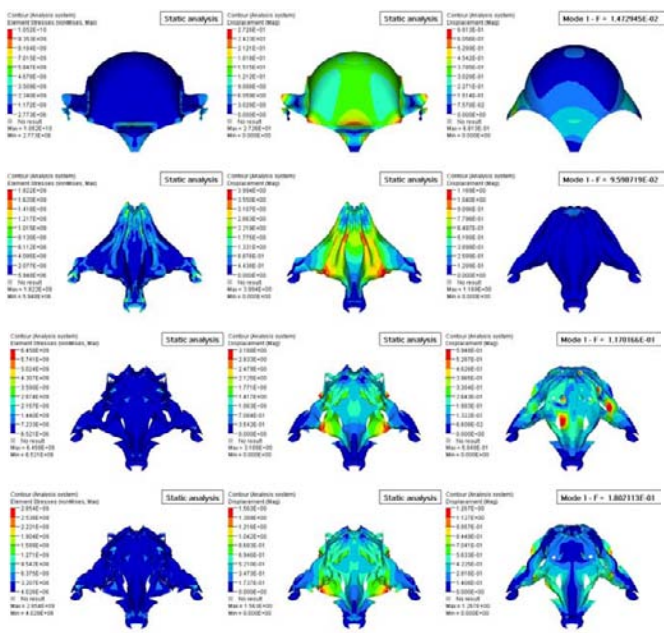

Figure 10: Comparison of analytical results for all shapes.

Analysis of the first transformation showed an improvement in global buckling behavior but also identified potential for local buckling in some surfaces. Local buckling indicates an instability that is restricted to a small region of the structure, as opposed to global buckling that indicates a wholesale (and usually catastrophic) change in geometry. The next iteration tried to improve global buckling further by connecting the lower areas of each arch and by introducing more shape in areas prone to local buckling.

Analysis of the second transformation again showed improved stiffness but the form still needed additional stiffening in the middle areas shown above as yellow and red in Figure 7. The final iteration increases surface connectivity globally by making smooth toroidal transitions across previously unconnected surfaces.

Ultimately, comparative analysis between all four geometries above shows that with each set of shape stiffening operations the structural performance increases significantly. The BLF has increased from 0.015 for the dome to 0.18 for the final iteration. The BLF for the second and third iterations is 0.096 and 0.117 respectively. This marks a twelve-fold increase in stiffness from the original geometry to the final geometry. Additionally, maximum displacements have also been significantly reduced from 27.3 units to 1.6 units, marking a 17-fold decrease in maximum displacements.

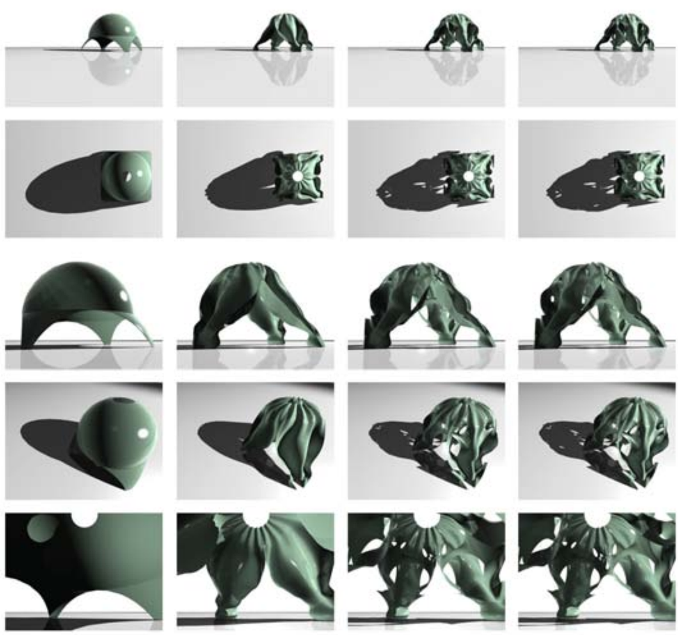

Figure 11: Progression of geometric transformation.

5 Conclusion

The process presented here can be taken as an analytical example for designers wanting to use material behavior and shape stiffness as primary drivers for designing and building complex surface geometries. FEA is a clear verification of the premise that 3D *shape* increases stiffness. Through this process geometric complexity can also be significantly increased. Formal aesthetics, design intensions/intuitions, geometry, material, and physical behavior have all converged in this process to produce a rich form where structure and skin, concept and construct, and process and product can be understood simultaneously through a continuum of surface.

Excluding the time necessary for geometric modeling, each of these FE analyses took approximately 30 min to setup, solve, and format the results. This is a powerful demonstration of how this method could very feasibly be incorporated into a daily design cycle. One workday could easily produce 3-4 geometric possibilities, depending on geometric complexity, with relatively accurate behavioral models demonstrating structural feasibility and potentials for further geometric development. Additionally, as true parametric modeling is quickly becoming normalized in design offices, one could easily imagine producing 10-20 geometric and analytical daily derivations for a project.

The deployment of this technology and these techniques as presented above is immediate. FEA is over 50 years old now and has already found its way into the background of many CAD packages that are used on desktop machines in architectural offices. Only desire is needed to implement this technique. The potential for future research lies in using FEA to design with non-linear, dynamic behaviors in mind. This method shows tremendous promise for developing even richer structures that are intentionally designed to accommodate, and even promote large-scale movement. Applications for such structures include seismic design, hurricane design, blast resistant design, deployable structures, responsive environments, art installations, et cetera. This research has only scraped the surface of what is possible for the future marriage of design and engineering.

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Practically digital

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Abstract

In the recent article "*Digital Complex*", Stan Allen observes a shift from virtual experiments in continuous surfaces and complex biomorphic forms to a more pragmatic interest in integrating the digital and the analogue, the real and the virtual, or the everyday and the fantastic. This paper presents design processes that utilize computers, small rapid prototyping devices in conjunction with traditional sketch ideation to fabricate realistic and creative form.

This paper posits that the observations made in Allen's article are currently reinforced pedagogically in that digital processes are moving away from the preoccupation with the virtual world and its representations; emphasizing instead the means of practical methods of digital fabrication and assemblage of the real. Undoubtedly, design education shows promise of reinforcing the strategic and operative potentials of the computer.

Similarly, the observations characterize the existing design methodologies of architect Frank Gehry as I experienced during my time working in his office. His process does, in fact, rely as much on the analogue as it does on the digital.

The research currently aims to define and demonstrate the benefits of using a combination of selected digital processes and analogue techniques in use with the design of a single-family, residential project. Again, rather than placing importance on the formal expression that digital design promotes, this paper argues for a new form of creative practice that digital technology enables.
Keywords: digital fabrication, digital design, digital/analogue processes.

1 Introduction

Between the idea and the building there is always a process by which a project is informed, explored and brought to life. Conventionally, this process starts with a series of sketches that evolve into a presentation model and/or hand documents that presumably describe the architecture of the building. As the computer

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became a familiar fixture in every design office, that manual process first lost its position to documentation and representation. The advent of ***C**omputer **A**ided **D**esign* or CAD technology emerged as a way to manage (what were thought to be) increasingly more complex projects. CAD did improve accuracy in drawing; increasing the number of "necessary" representations and time involvement in a set of construction documents. The increased time spent planning and managing the documentation created a situation in which technology ultimately diverted the architect's attention from the design process itself. As a result, design exploration of the virtual world remained (for the most part) separated from reality of the architecture and building industries.

The "hand" became even further outdated with the move from a Cartesian geometry to one based on NURBs (short for ***N**on-**U**niform **R**ational **B-S**pline*). The digital decade of the 1990s saw in Gilles Deleuze via Lynn [3] a prophet of the morphing, warping, and complicated curvatures of virtual space. This fascination upheld a preoccupation with paperless, un-built plasticity of virtual form and explicit digital design protocols.

Yet, Pfeiffer [2] claims culture is already "post-digital" due to its ubiquity. To concur, architecture practice and pedagogy are showing signs of its move beyond virtual "reality" as its main preoccupation. Indeed, understanding the technical and practical limitations of digital technology trumps the interest in a computer's ability to generate formal innovation and virtual effects. The mystery behind "the digital" has been codified; diminishing such notions as Flusser's [4] "apparitions of computed point elements floating in nothingness".

2 Academia and the acronyms

Pedagogically, an idea can now be informed and explored through the processes of digital fabrication [5]. Architecture schools all over the world are trolling for students with promises of the biggest CNC mill, the greenest CAD/CAM printer or the latest laser cutter. The intention is to make digital design a physical reality; searching for future tangible attributes of abstract thought that were until recently trapped in virtual "reality" image. Coincidentally, the difficulty for young designers is not in how to use these available technologies, but rather which to use and when.

2.1 CAD needs CAM

CAD/CAM abbreviates the overriding relationship of *Computer-Aided Design* to *Computer-Aided Manufacturing*. By integrating CAM with CAD systems, the architect regains control of design AND making. This control means the architect can potentially bypass the builder and talk directly to the machine. The relationship has the ability to produce fast and efficient prototypes, as well as building components straight from a 3D virtual environment. Novitski [10] proclaims this ontological shift to be quite profound, given that these objects of resin, polyester, or other (presumably) full-scale building material are crossovers from another plane of existence—data bits in the virtual world.

Rapid Prototyping (RP) is a term synonymous with CAD/CAM and again automatically constructs physical objects through subtractive or additive methods. Today, architectural explorations have primarily co-opted this technology to visualize during the conceptual stages of design when dimensional accuracy and strength of prototypes are not a primary concern. The word "rapid" is relative: construction of a model with contemporary machines typically takes 3–72 hours, depending on model type and size. In brief, this process takes a virtual design, transforms it into virtual cross sections, and then produces each cross section consecutively in physical space. It is a process where the virtual model and the physical model correspond almost identically.

2.1.1 Additive processes

Three-Dimensional Printing (or 3DP) is a low-end version of additive fabrication technology; optimized primarily for speed and cost efficiency, making it suitable for quick physical models. In additive prototyping, the machine reads data and lays down corresponding successive thin layers of plastic, wax or some other engineered material, and in this way builds up the model from a long series of cross sections. In the end, these layers are fused automatically to create the final shape. The primary advantage to additive construction is its ability to create almost any geometry (excluding trapped negative volumes). One drawback is that these machines make smallish parts, typically smaller than an engine block.

2.1.2 Subtractive processes

CNC or *Computer Numerical Control* refers specifically to the computer control of machine tools for the purpose of manufacturing repeated complex parts in various materials. In this technique, the machine starts out with a block of material (typically foam, wood or plastics) and uses a delicate cutting bit to carve away, layer by layer to match the digital object. It is similar in concept to a sculptor carving away at the surface of a block of marble. Consequently, the subtractive method is older and less efficient. However, curves are as easy to cut as straight lines and are capable of doing large scale projects. Complex 3D structures are relatively easy to produce, and the number of machining steps that require human action has been dramatically reduced. Complex shapes and forms with undercuts are more difficult to accomplish, but are typically made in parts that fit together. Serendipitously, this process can give way to chance as a routing bit receives a glitch in the data and repeats an unintentional part, fig 1.

2.2 3D Mapping

The cartographic process rests on the premise that there is an objective reality and that we can make reliable representations of that reality by levels of abstraction. Digital mapping relies solely on the data and the technological aptitude of its controller.

2.2.1 Laser-cutting

Like rapid prototyping, Laser-cutting takes 2D outlines from virtual designs and "cuts" or etches each line in physical space. Analogue templates can be extracted from the physical models, drawn in CAD and then laser-cut back into physical space. Again, it is a process where the virtual content and the physical model correspond identically. When used for topographical sections, laser-cutting maps out 3D space. The laser-cutter can cut a variety of materials, but is best applicable to wood, paper, plastic and acrylic.

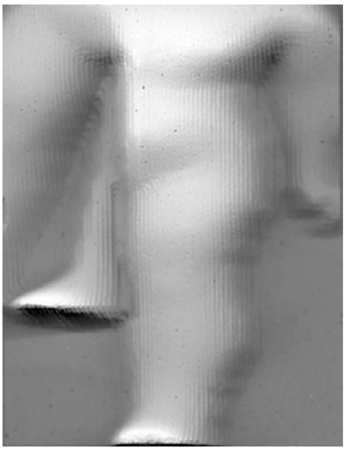

Figure 1: CNC fabrication.

Figure 2: LIDAR scan.

2.2.2 LIDAR

Laser Imaging Detection and Ranging technology is used to digitally map physical objects in space. Vertical laser pulses determine complex geometries and gathered unbiased data in the form of a point cloud. A point cloud is a set of three-dimensional dots describing the outlines or surface features of an object. The point cloud is then transferred to a triangulated 3D surface for manipulation and fabrication in a subtractive RP. Alternatively, the triangulated virtual model can then be reduced to interval cross-section profile information to administer to another fabrication process, like laser-cutting, fig. 2.

3 Gehry and "the digital"

Phenomenology as a design philosophy has its basis in the physical and tactile experience of building materials and their sensory properties. Norberg-Schulz [7] relays it as an approach that urges a "'return to things' as opposed to abstractions and mental constructions". Frank Gehry conforms to this philosophy in his digital making; a process that is unique in that it expands on the use of physical models to build digital architecture [8].

This inverted process of creation gives way to chance and the unconscious results of everyday phenomena acting on the design. A coffee cup serendipitously left on a model could easily become part of a project, or

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accidental breakage of a model could very well give rise to its new shape. The resulting order shows an organic awareness that diverges from the formal logic-sharpened-in-static object concept.

3.1 Analogue methodology

Vidler [8] claims that the design of the Guggenheim Museum in Bilbao was "entirely a product of software". On the contrary, Gehry's design method for that project and every other is embedded in a technique of analogue modelling which allows numerous iterations to be studied quickly and effectively. These models serve as sketches, massing studies, formal studies and ultimately as 3D database. From the earliest sketch stages through to the development of construction documents, the physical model drives the process.

3.1.1 Sketch ideation

The sketch is the starting point for a project's design. It serves as one of the early defining elements to direct the design and is a tool that Gehry returns to throughout the process. Typically, this sketch is almost a child-like, hand-drawn gestural figure of an elevation or plan. The goal of the model-maker is to capture the spontaneity of the first sketch and the human dimension. In this practice, the computer screen is never considered a platform for design. The models are understood as idea diagrams for communication between Gehry and his team.

3.1.2 Scale models

At every stage, scale models are used as a guide to designing and making the full scale architecture. Physical models are where the sketch ideas take form and shape and where accuracy is critical. The more accurate the scale models, the more efficient the final built outcome. The projects start with site and block models that are used to further describe location, program, function and volume. The wood blocks are cut by hand, but the site models employ laser-cutting technology to cut the topography and to etch detail of context information. Once an idea is sketched out volumetrically, the process of shaping takes places with additive paper and glue.

3.1.3 Templating

Rather than using the model as a descriptive tool for final presentations, Gehry has developed a methodology for the "working" model that allows for quick transformations and studies of varying concepts. The models can be easily glued, torn, cut and modified. Every iteration requires a formal "mapping" before any modification takes place. These templates catalogue stationary spatial locations, shape and form; while providing documentation of a ruled surface pattern. A geometrical surface is ruled if through every point on that surface there is a straight line that lies on it. Registration to a Cartesian grid on each site model also prepares the model for transferring the real data into the virtual.

3.2 Digital processing

While the physical models remain the primary place for design exploration, computer models are also utilized to develop the complex forms and provide technical information.

3.2.1 Digitizer

Periodically, the scale model is digitized to create a virtual one in order to extract more precise information about the building. The digitizer, fig. 3, converts the position of a point on a surface into digital coordinate data. The coordinates of the virtual domain allow for analysis and adherence to project limitations such as exterior surface areas.

The physical models test the likely performance of a design and constructability at an early stage without the expense of building a full-scale prototype. Because the characteristics of model making materials (like thickened paper) mimic those of the full-scale building, inherent surface intelligence is being designed in the physical studies. A developable surface is one that can be flattened onto a plane without distortion. All developable surfaces embedded in 3D space are ruled surfaces and thereby allow constructability.

Figure 3.

3.2.2 Parametric modelling

Once a model has been "digitized", it also acquires malleable expediency in the computer by way of parametric modeling: dimension-driven modification of building components, embedded parameters, rules, and constraints. The computer model then develops in a 3D database used for the creation of the construction documents and to aid with required performance analyses such as structural and wind loading.

The ability to simulate whole buildings in the computer-including geometry, materials, lifecycle cost, schedule, and energy use-is thought to be "smart building". Virtual space becomes the testing ground for different potential realities and evaluation for material implementation. Information derived from material constraints to site conditions can be constantly fed into the intelligent computer model to provide an accurate update, which in turn introduces feedback into the overall design, and change can then be registered in the detail. Therefore, simulation becomes a way of assessing the developing performance of the project and the limits of a spatial system through a direct engagement with the underlying geometry of the design.

After the computer model has been adjusted to meet the limitations, information is extracted into 2D CAD documents. These become the floor plates and ruled surfaces for another physical model to check any changes in the computer model and accuracy of the digitization. While there is no definitive conclusion for an idealized form, the process allows for themes of craftsmanship and design overlap through structure, material, pattern, geometry, and parametric control.

4 Single-handed design process

As a solo practitioner now, cultivation of an expedient relationship with laser-cutting and additive rapid-prototyping digital technologies along with analogue processes (learned from working with Gehry) then informs and expedites the current design of a single-family, prefabricated residence in Barbados, West Indies.

In addition, the technological conditions of that country, actually being of high-standard, will allow for full-scale, digital fabrication of the house through parametric modelling. Our overseas collaborator, Preconco, Ltd., [12] has appropriated the use of digital production processes in conjunction with pre-cast, concrete construction methodology. This collaboration will assess their digital methodology by way of a structurally atypical design approach to a detached dwelling.

4.1 Design in process

Due to geographical constraints between the client in Barbados and my self in New Zealand, the design process incorporated transfer of documentation and models through the internet and postal system; necessitating small scale, modelling/prototyping for design update and review. Being a solo practitioner, rapid-prototyping facilitates the making of physical design models.

The design was initiated by a CAD file that 2D showed the terrain to be quite steep; forcing topographical site study models became a first priority. Laser-cutting expedited this act of making through quick production of multiple site model iterations. Vector information from that CAD file, including tree location and drip-line, is etched or cut onto matte or cardboard. The laser-cutter registers information that traditionally gets left behind in the manual model process. Block studies show volume, materiality and coded function, fig. 4.

The design began by adhering to Kepes' [9] visual concept of classical physics, which describes objects existing in three-dimensional space and changing locations in sequence of absolute time. Studies of digital/analogue models developed "lines of force". These directives capture and produce the sensation of movement even if the spatial position of the house will be stationary and formally static, fig. 5; thus, animating form without the use of NURBS.

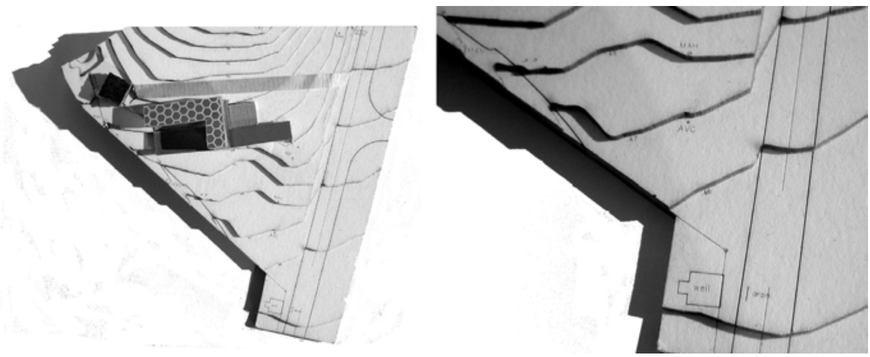

Figure 4: 1" = 500' scale laser-cut study model.

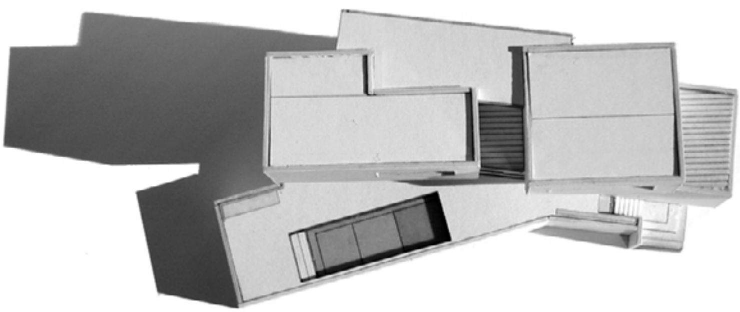

Figure 5: Laser-cut design model.

Furthermore, the site study models locate exact position of form. This position is documented via raster image produced on an everyday flatbed scanner; updating the CAD files with formal information. The massing is developed in virtual 3D to study sun angles digitally. The subtle movement of form also corresponds to this sun angle study developed through physical models and the digital database.

From the same files used to cut the site study models, two additional (larger scaled) site models are laser-cut for schematic design- one to be used by me throughout design and one for the client and local consultants. CAD documents are developed at a schematic level for square footage count and functional placement of rooms. The 2D CAD floor plans then facilitate formal testing patterns for analogue model making via exported files to the laser-cutter.

By exporting the 3D AutoCAD file as a *.stl* file, the 3D virtual model is investigated through *Stereo Lithography* (or STL) - a form of additive rapid-prototyping. This allows the production of a model that fits in a four-inch cube for under US$150. I believe much less time and money is invested than if I had built the models physically myself. The result is an amazingly accurate and sturdy model, with detail that could not be achieved by hand. The physical model becomes the most important design document because it is the information by which the client can "read" and (more importantly), the physical model verifies the design of the 2D CAD documents and solid STL model that are being repeatedly fabricated. These files serve as database into Preconco's BIM modeling package for full-scale fabrication.

4.2 Fabrication

In support of Benjamin's [11] claim, the immaterial of the virtual world must materialize to have any real gravity. Now that the architectural design and construction relationship is enthusiastic about building and/or fabricating digitally, design, representation, analysis, documentation, and production are becoming a relatively seamless collaboration. The intention and challenge for this design process collaboration with Preconco, Ltd. technology is whether the use of *Building Information Model* or BIM can reinvent the ideals of master craftsmanship that CAD seemingly abandoned.

BIM or parametric software is now available to any architect and builder, not just the aeronautical industry and Frank Gehry. Last minute revisions to the intelligent virtual model are acceptable because changes will be automatically populated throughout the digital project. For this practice, introducing the BIM model process to schematic and design-development phases are potentially doing away with the construction document phase as a separate entity. When used in conjunction with technology like the laser-cutting and stereo lithography, the design phase continues up until the moment the information taken from the BIM model gets directly 3D "printed" for construction assembly. For this reason, the adherence to phenomenal "lines of force" can be practical in that the architecture employs prefabricated component pieces as a system of assembly.

Inversely, Preconco's replication of construction in the virtual environment will demonstrate difficulties and allow conflicts to be identified and eliminated before any building begins. Any such necessary adjustments to the design will constitute another STL model for client review. Significant savings in time, money, and materials are amongst the expected economic, social and environmental outcomes.

5 Conclusion

Today, the computer is not a new technology to be celebrated or deconstructed; it is simply a fact, a tool like any other. Realization of the immaterial relies on the creation, reference to and (most importantly) physical distribution of digital "content". After a decade's immersion in the image, the virtual and the "merely" formal, it seems that common sense has returned to the digital process.

A generation of designers that were educated in digital technology are no longer seduced by its formal effects or intimidated by its complexity. Designers from any generation need to know when something is improved through technology, but certainly should be not blind to the fact that technology sometimes is not always the appropriate or practical answer.

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The Virtual School of Architecture and Design

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Abstract

The Virtual School of Architecture and Design – VS – is an innovative 3-D virtual environment. The environment was created to provide the perception of an advanced "real" school of architecture. The studios, laboratories, library, classrooms, galleries, theatre and movies were designed with "learning objects" and other advanced tools. There are interactive spaces to develop intellectual and creative skills. The activities are designed to integrate concepts and practices in the architecture field with an interdisciplinary curriculum: Humanism, Technology, Creativity and Innovation.
Keywords: digital architecture, virtual school of architecture, online education, e-learning, Creativity and Interactions online.

1 Introduction

Digital Technologies are revolutionizing the practices of teaching and learning at universities all around the world. For decades now architects have struggled with how best to address the needs of students. Interdisciplinary studies and collaborative design in education promote significant changes to architects and educators. Technology and the integration of internet and multimedia offer teachers a tremendous opportunity to put their students in touch with other cultures, a well as to teach them how to manager information: collecting, analyzing, interpreting and presenting data. Powerful simulation engines will present verisimilitude to educational experiences that is unavailable in twentieth-century schools. Students will be able to test sophisticated designs and hypotheses or verify details like architectural forms and natural illumination, colour system or understand complex urban structure.

Like a real university, the Virtual School of Architecture and Design – VS – presents qualified spaces, interaction and administrative resources.

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2 The Virtual School of Architecture and Design – VS

The Virtual School of Architecture and Design – VS – is an innovative 3-D virtual world. The environment was created identifying discrepancies between courses online and the special needs to attend architecture area, in particular creativity and expressive development spaces.

2.1 The simulation

Simulations are coming of age. The Virtual School of Architecture and Design – VS – was designed as a creative space with studios, classrooms, laboratories, library, galleries, theatre, movies and a special self knowledge centre to improve differentiating curricula and develop personal skills. The spaces were concept in linear, cyclical, open, and open-ended modes. Linear mode suggests spaces where the students will watch videos, films and clips or read articles, case studies, texts, and e-books. Cyclical mode was applied to attend repetitive actions in order to provide complex understandings about phenomena. For example, students understanding theory of colour light at colorimetric laboratory. The lab has three different fonts (red, green and blue), fig 1. The student will learn how to obtain many colours with additive synthesis addicting more or less luminosity. To represent faithfully, this activity was linked to a real problem or case and the content can transfer to real life immediately. Open mode content was designed to creative spaces, studios of design, ateliers. The activity doesn't require attending a goal. The problem is presented and you can solve by hundreds and unrestricted solutions. Open-ended mode was applied to design spaces with multivariate cases involving several keys variables. The students solve problems relating knowledge and strategies. For example: urbanism and planning laboratory (multiple keys and variables).

Figure 1: VS. Laboratory of Colour: mixing lights.

2.2 Metaphor of Architecture and Modelling Spaces

To build metaphor references, the architecture style remembers the real world. In many situations the space presents new visual codes and modern syntaxes because they must be very attractive and dynamic in order to motivate students. The subject is architecture so everybody, students and teachers hope other sensations and coherences at virtual space, especially in web design. The Virtual School of Architecture and Design – VS – was developed to give correct perceptions. Starting with the transformation of the usual entrance hall and its combination with types of typologies, the main entrance was built to encourage people to have experiences with art and architecture, fig. 2. But once inside the atrium students can go to art gallery, theatre, movies, auditorium and coffee shop. The pronounced presence of natural light is a lesson about sustainable and ecology architecture. Paradox is used to make what is invisible, visible and the presence of past and present models. Placed around the central building were located library, study rooms, offices and meeting rooms, ateliers, studios, laboratories, and classrooms.

Figure 2: VS. Main entrance.

2.3 Interaction and methodology

The activities are designed to develop interpersonal relation between students, creativity to find solutions to case studies or specific problems. Teachers can organize groups of students or “learning communities” to discuss and analyze cases. The interaction encourages students talking about ideas and concepts. The VS create a strongly collaborative team because there are high quality moments of interaction. Chris Dede [1] wrote hundreds articles about knowledge networking and artificial realities. It involves creating a community of mind. Through sharing disparate data and diverse perspectives, a group develops an evolving understanding of a complex topic. Over time, the group’s conception of the issues continually expands and deepens, at times broadening the range of fields and experiences seen as relevant. Architecture is a mastery of complex multidimensional information.

The spaces help teachers to organize activities, clear the instructional objectives and goals and present excellent feedback performances. The cultural and interactive activities are supported by tools and resources to go beyond the limitation of the self resolutions. Beyond the alone "online students" there are interactive spaces to develop cooperative work. Forums, Galleries of Art, Theatre, and Travel Agency can allow spontaneous encounters with other networked participants, fig 3.

Figure 3: Theatre.

The difference between real and virtual school is the core curriculum. The courses online must be tremendously challenging to these students in order to keep them very motivated. It's necessary to relate theoretical concepts and practical activities. If they do not understand their value or see relationships between these courses and their majors unfortunately they will give up. To improve activities

The Virtual School of Architecture and Design – VS – adopted case methods. This methodology helps students apply theoretical perspectives to real-life situations. A case study is the type of research most applicable to the average students and can be of extreme importance in evaluating system. Because students move from theory to practice, it's allowed learners to connect with their academic values and the knowledge for its practical utility.

In this case study, students are introduced to concepts about techniques and ceramic control. The lesson was designed to teach introductory materials majors about the ceramic tiles in quality control. Working in small groups, the students analyze a variety of information.

They will visit four virtual laboratories to test samples. The technological services offered by the laboratories may be divided into four areas: analyses and testing, finished product laboratory, quality guarantee and information and documentation. The laboratories have appropriate virtual scientific instruments to promote deep understanding about procedures. The finished product laboratory is accredited by certification to carry out standardised testing on ceramic tiles, ceramic materials for construction and sanitary ceramic appliances. Like a real laboratory, the Information and Documentation Unit present the information needs that arise inside and outside the lesson, as a result of the scientific, technological, teaching and training activities carried on. To do this, all the documents published about ceramic technology are selected and compiled. With the result they will find multi aspects and they will judge if the floor ceramic tile can be accepted by civil constructors, fig 4.

Figure 4: Case study: floor ceramic tiles.

2.4 Travelling across the History of Architecture

The internet played a major role in the evolution of society and in the educational process. As a tool for transformation, it improves knowledge beyond geographic boundaries. Disciplines like History of Art, History of Architecture, Urbanism and correlated can visit past and present locations and investigate cultural and technological characteristics.

With Google Earth [2] and similar resources, students can study morphology, geography, topography and landscape. They will take a virtual tour investigating multi aspects about the architecture reference. Teachers can ask students to draw maps of the local area and describing the political and physical boundaries and the reasons why the political boundaries were created in the past and at present times. They can identify the relations between topography and architecture, the city, and the surrounding communities. In the Google Earth map there are links with National Geographic data base [4] and students can investigate many aspects about civilizations, fig 5. Students can read related links and take a tour in Egypt's Ancient History (From the Valley of the Kings to the Great Pyramids to Zigzag in the Delta, discovering fascinating facts about mummies, and other ancient mysteries on the official site of Egypt's Ministry of Tourism and UNESCO) [3].

Several appropriate technologies that can be used, as well as the shortcomings of previous methods. This technology doesn't understand as media through videos and other resources like reality representation, photos in high resolution, realistic environment. Students can manipulate, see different points and details.

In other case, for example Knossos – 3D Virtual Reality Tour, developed by British School of Athens [4] visitors can have full view of interior and exterior of architecture, from every angle and can virtually examine details, fig 6.

Students can visit Museums and manipulate pottery, sculptures, and objects. Virtual Reality (VR) technologies provide an original resource for enhancing

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user visualization of complex three-dimensional objects and environments. For teachers and architects the acknowledgement that spatial ability is important, it is meaningful to identify the spatial abilities of students. With virtual reality resource they will manipulate sculptures and other museums resources. They can watch specific videos or draw drafts to study details or share sketches. For example, students can understand The Odyssey context examining details in the pottery at Virtual Gallery [5]. With QTVR can Students can manipulate all selected ceramic identifying chapters of the adventure, fig 7.

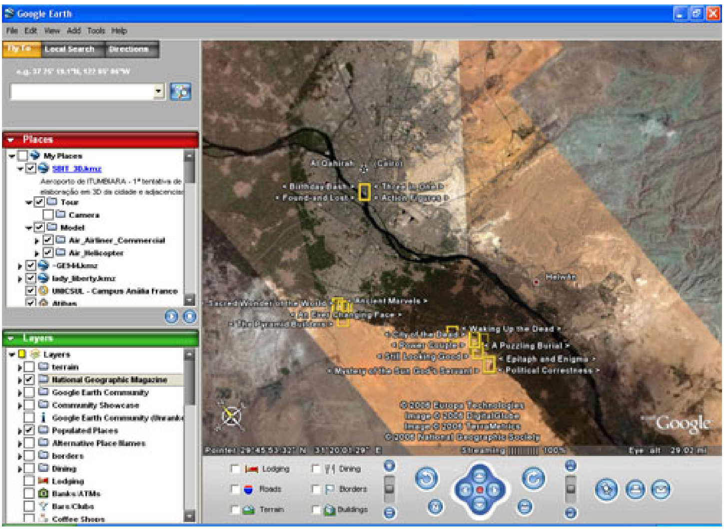

Figure 5: Google Earth – investigating Nile Civilization.

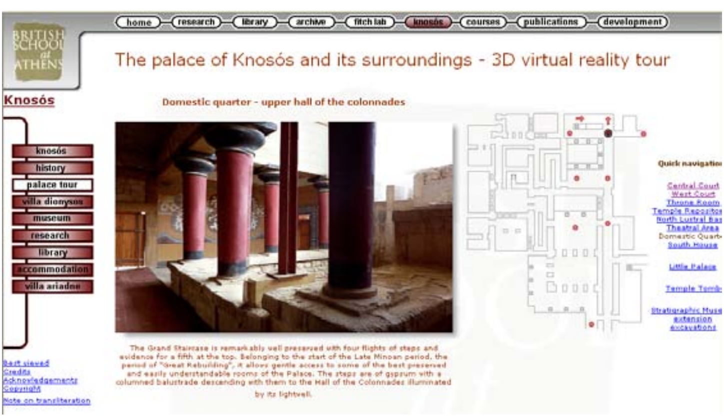

Figure 6: Knossos – 3D virtual reality tour.

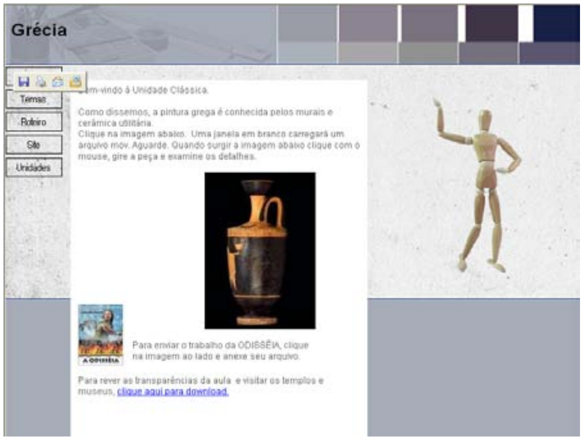

Figure 7: Telling a history about Odyssey.

Figure 8: Build a Medieval Arch.

Linking learning objects, students will simulate constructions process. Students can rebuild an arch or understand process and recovering ancient techniques from the past. There are a lot of educational sites and resources like Society and Culture: Architecture from BBC [6]. For example, students can understand how medieval arches were built, fig 8.

3 Cultivating creative spirit

The Architecture and Design environment have been full of innovation. New constructions materials, technologies, whole new civil industries have emerged. Creativity is the historic route to architecture growth. Creativity seems to be useful in any field of life, in arts, science, and business. New ways of thinking that express creative solving of problems is motivated. The pedagogic model of Virtual School is the collaborative learning. Cooperative learning skills promote meaningful social interaction through problem solving among students and teachers. Collaborative learning encourages students to take responsibility for their own learning through structured activities, researches and task assignments, and sharing results. According to Gokhale [7], the term "collaborative learning" refers to an instruction method in which students at various performance levels work together in small groups toward a common goal. The students are responsible for one another's learning as well as their own. Thus, the success of one student helps other students to be successful.

4 Evaluation

Architecture is inherently multidisciplinary, and the curriculum should also reflect that, and lessons should be integrated with other subjects. The curriculum model engages students in the examination of a real world issue with reference to the seven domains – Arts and Creative Expression, Science and Technology, Physics and Maths, Political Environment, Sociology, Economic and Diversity, Ecology and Environment. Participants seek to show the interrelationships of the domains and the intricate balance of the domains within a given issue.

Grassian [8] presented alternatives to evaluate web sites. It can be adopted by teachers when choose sites linking disciplines in order to find intrinsic value. Assessment models that provide information about each learner's understanding, and based on the way learners respond to questions designed to probe their understanding; teachers can redirect learning activities that correct these errors.
Assessments of learning that are consistent with their intended use with multiple meanings. Teachers can recognize results designed to provide feedback that will improve best practices online for new purposes and the type of assessment needs to match its intended use.

5 Conclusion

The most important issues identified from the perspective of collaborative learning were that the computer system should facilitate for: mediation of complex collaborative activities such as critical discussion, establishment of a common frame of reference; presentation of individual contributions to a group product; mediation of messages; mediation of activities; organization in division of work; and discussions about results. Several of the lessons as proved to be infeasible in a realistic use situation. This is approached by exploration of the research question: What are the possibilities of internet related to performing collaborative activities in Virtual School of Architecture and Design? Technology available was applied in all pedagogic and research situations. Students need to be able to think creatively, solve problems, present new solutions and make decisions as a team. Therefore, the development and enhancement of critical-thinking skills through collaborative learning is one of the primary goals of technology education.

One important characteristic of this plan is the dissemination of the technology in the faculty. By providing technology that already is familiar to the students, the students' efforts related to learning how to use the Virtual School to improve knowledge. Teachers, who all were experienced internet users, found the Virtual School of Architecture and Design system easy to use. The Brazilian participants in the prototyping project, however, had considerable problems related to the telecommunications connections technology (phone or cable access). The internet has yet to penetrate the Brazilian society; a large section of the population does not have access to home computers by cable. The rapid increase of the use of the technology in education, however, is promising in this respect.

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Operative representation and the digital

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Abstract

Animation software promotes new architectural design practices where form making is presented as a 'clean' indexical translation of contextual data or information. The formal outcomes typical of this design method implicitly resist the foregrounding of representation, either as a depiction or a tool, as a subject worthy of research. Given the ubiquity of the image this rejection has a capacity to create a rupture between the profession and the wider community. The objective of this paper is to provide a critique of the implicit theoretical position animation software has to representation and explore how the application of other software can be used in conjunction with strategies and techniques aimed at a critical engagement with the usage of the image present within this broader social context. In doing so the discussion will draw on texts, including those of Robin Evans and W. J. T. Mitchell, as well as built projects and outcomes of design-based research.

The allure for abstract indexed form is evident of a longstanding architectural 'iconophobia' towards the image and as such embodies a very particular ideological bias that restricts the agency of architecture to contest its conventionalisation and subsequent deployment as a political tool or device of the market. In light of this an argument will be made for the generative capacity of the digital to act as a way of operatively engaging with the image's representational 'job'. The paper is not therefore opposed to the digital but against certain design practices that treat both the image as irrelevant and the modes of representation as an unproblematic and neutral transformative space.
Keywords: design methods, processes and creativity, digital design, representation and visualization, knowledge based design and generative systems, social aspects.

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1 Operative representation and the digital

The adoption of animation software in architectural design practice has instigated a mode of form making that is promoted as a ‘clean’ indexical translation of contextual data. The argumentation accompanying such design action significantly recalibrates architecture’s relationship to representation in two noteworthy ways. The first, somewhat paradoxically, normalises the instrumentality of the digital by imbuing animation software with such sophistication that the virtual space of the computer ‘drawing’ is rendered as a benign ‘site’ of transformation. The second is that the issue of figurative representation is explicitly condemned as an irrelevant and anachronistic architectural concern. Yet the abstract, non-representational projects emerging from this design practice seem inconsistent with the wider community’s understanding of architecture, where the currency and ubiquity of the image unquestionably reinforces an expectation for it, via a figurative facility, to impart identity and meaning to the artefact. The paper, drawing primarily on my own post graduate design based research, aims to consider these conflicting ambitions for architecture as motivation to re-assess the role of representation in order to promote operative design strategies and techniques that engage critically with contemporary issues present within the public arena. Integral to this argument will be the promotion of a mode of digital design practice that openly acknowledges and exploits the image’s figurative ‘job’ through the generative potential within all digital tools.

Undoubtedly the re-conception of representation from illustration and signification to generative tool offers a rare moment to re-think the processes and methods by which architecture is made. The instrumentality of these ‘drawing’ techniques regularise an experimental engagement released from the preoccupation to legitimise design action. Yet the argumentation for non-representational form obviously witnesses a discomfort with representation and image as demonstrated in the following quote by Greg Lynn.

“The shift […from meaning to machine…] is the primary explanation for the apparent alliance between certain aspects of Deleuze and Foucault’s discourse and many contemporary architects now weary of representational critiques spanning from stylistic postmodernism to deconstruction…” Lynn [1].

This trivialising of representation can be interpreted as a criticism of the projection onto architectonic form the linguistic model underpinning Postmodern and Deconstruction theory. In making this point Lynn implicitly accepts that representation falls into such a framework, in as much as such projection can only be manifest as an imagistic symbolic device. Thus conceived of as an act of figurative labelling, the image’s generative potential is trapped to the ‘job’ of attaining semiotic closure through a ‘naming’ or re-presenting.

It is possible to contextualise this semiotic limiting of the image as participating in a recurrent iconophobic architectural tradition where the desire for intellectual depth, often linked to a transcendental search, which asks the architect to go beyond the surface of things. In this light the shift from ‘meaning’ to ‘machine’ goes further than the machine’s facility to abstract, process and reconfigure complex real world data. Drawing on W. J. T. Mitchell, this conventionalised interpretation of the image as a literal or 'natural' sign imparts an immediacy and directness that automatically evacuates the possibility that the image might occupy a generative space. In contrast Lynn's view of the 'machine' is more akin to Mitchell's discourse on the conventional status of the word, which acts as "…the artificial, arbitrary production of human will that disrupts natural presence by introducing unnatural elements into the world…" Mitchell [2]. Unlike the image which is wedded to that which it re-presents, animation software is deemed to be sophisticated because of its ability to productively respond and accommodate these artificial cultural constructs, and to do so through the use of process where form making is an emergent action rather than a pre-determined re-presentation.

As a consequence any potential for architecture to impart meaning resides only as a second order outcome. To quote Lynn again:

"The use of parameters and statistics for the design of form requires a more abstract, and often less representational origin for design. The shape of statistics, or parameters, may yield a culturally symbolic form, yet at the beginning, their role is more inchoate." Lynn [3].

Obviously the central architectural concern is the parametric capacity of animation software to capture the contingent and temporal. While careful to state that the digital is an artificial rather than organic process the trajectory of the argument constantly attempts to 'authenticate' this working method by associating the process with terms like 'natural' and 'evolutionary'. As Lynn writes "Animation… implies the evolution of a form and its shaping of forces; it suggests animalism, animism, growth, actualisation, vitality and virtuality…" Lynn [4].

This design practice is predicated on a geometric engagement with the contingencies of the real where static platonic form is replaced with the dynamic facility of the spline. Obviously, what is under scrutiny is the form and method of application rather than the issue of geometry itself. The promotion of the spline acts only as another manifestation of the desire to establish legitimacy through asserting a geometric underpinning the real. Therefore while one might tolerate such a correspondence on structural grounds the deployment of the spline to embody other forms of information serves only to complicate the status of the spline. Furthermore, the translation both through the mode of 'drawing', in the form of the diagram, and its material conversion questions the validity of such claims. In light of these realities the spline performs a representational 'job', by merely 'standing in' for information [5]. In keeping with Robin Evans's thesis, the mediating affect of the digital tool clearly locates its 'drawings' as a significant generative 'site' in the production of the artefact [6] (Translations from Drawing to Building best develop this thesis on the 'drawing'.)

The mediated nature of this information cannot, therefore purchase validity for the artefact. The unproblematic acceptance of information as valid or 'natural' also demonstrates a certain lack of criticality, preventing any contestation of either the status of the data and the worth of the temporal shifts it attempts to embody. Unable to fold in the complexity and deviation within the data this information is often converted into the statistical average, resulting in a privileging of the normative over the particular. The agency of the diagram in this process functions more akin to a kind of modernist reductive abstraction best identified by John Rajchman's in the essay Abstraction [7]. This reductive 'averaging' converts architecture into a prosthetic device, instituting an autonomous design process entrenched within the linear trajectory of a procedural logic. The jettisoning of the qualitative can therefore be seen to run counter to any claim of embedding the contingent and the temporal.

The erasure the impact in the process of translation simply re-sublimates the generative capacity of the tools and privilege instrumentality and production over any critical consideration affects or effects of or on the artefact. The contingency of the digital 'drawing' questions any investment made in text to establish such authenticity and instead necessitates a reconsideration of the potential of other software to index and process temporal information. This is not to deny that animation software still retains an architectural potency worthy of pursuit. The point is that the suppression of representation works only to restrict architecture's engagement with issues of signification and the generative capacity of all digital tools. Exactly at the moment when these tools offer a new space of experimentation, capable of addressing a wide range of architectural concerns, the compulsion for legitimacy threatens to conventionalise their deployment. (The sources of this anxiety are in the end unimportant in that they mask the effect of this compulsion.) This also converts the 'drawing' from a space of opportunist engagement to a site of embedded ideology.

The persistence of the figurative within the wider community ensures it relevance as an important architectural concern. The following quote by journalist, Miranda Devine, on figurative readings contained within the National Museum of Australia (NMA) by Melbourne Firm Ashton Raggatt McDougal (ARM) underscores this expectation for buildings to possess a narrative capacity.

…[T]he national identity portrayed by the museum was designed to make visitors hang their heads in shame.

As one museum council member said, it made "people leave the museum hating other Australians".

Little can be done about other attempts by the architects to falsely equate Aboriginal history with the Jewish Holocaust in Europe. The imagery is embedded in the design, copied in part from Daniel Libeskind's Jewish Museum in Berlin, which combines a broken Star of David with an SS symbol.

But, under Morton, what he calls the "black T-shirt" view of Australian culture is being replaced by something more complex and accurate.

"I want people to come out feeling good about Australia," he said... Devine [8].

Implicitly Devine accepts that representation, as an act of signification or naming, is one of architecture's 'jobs'. The question is not whether architecture can or should possess narrative facility but more an issue what it should be allowed to say. Architects may dismiss this as being unsophisticated but the context in which this expectation exists has a tendency to reassert itself irrespective of whether or not it is acknowledged in the conception, production or promotion of the artefact. Ultimately the failure to recognise this social expectation can only create a rupture between the profession and the community.

This should not be misconstrued as an argument for a return to figurative representation as a central architectural issue. The conventionalising of the tectonics of architecture to achieve semiotic fidelity between the sign and what it attempts to re-present traps the artefact's agency to the act of saying. This is particularly problematic given the mass media's capacity to configure new semiotic codes as a mechanism to propagate the specific political and commercial agendas of that minority controlling its production. After all self-interest necessitates a thinking that replaces the complexities and contradictions of the social by universalising narratives. When Devine expresses the need for architecture, as a public act, to 'make good', the ensuing imagery serves only to normalise the ideological positions of those officially sanctioned narratives. The architect's complicity with this conceptually conservative framework extends beyond the issue of political censorship. Just as importantly the figurative, as a codified set of pre-inscribed signifiers, automatically limits all formal and spatial possibilities to a constant redrawing or re-presentation of these same signifiers. As such the figurative's 'job' of 'saying' or 'naming' evacuates representation, as an issue of both meaning and tool, of any generative experimental potential.

This is not to exclude the possibility that representation, particularly as an issue of signification, possessing a generative facility. In the essay Unreal Estate, prominent Australian architect, Carey Lyons, suggests that the strategies and techniques associated with the image's social and cultural function can operatively rethink the making of the built environment. To quote:

"The physical necessities of the industrial city…are being replaced by urban 'forces' that lack a physical nature: mass media, information technologies, a culture of consumption and services… This city of images, modern myths, and commodity spectacles is a strange and complex matrix of ephemera that are the conceptual and cultural substance with which to make our cities." Lyons [9].

It would be easy to dismiss this position as a simple extension of Venturi's promotion of the image's semiotic fidelity to that which it attempts to 'stand in' for. However, the essay's advocacy for the appropriation of imagistic strategies, tactics and techniques from the 'radical artifice' Lyons [10] of the contemporary social context offers the image productive value. Such strategies and techniques can be considered operative because its agency is focused on the production of alternatives more than the relating of some prescribed narrative. This thinking is evident when Lyon's writes that these "…strategies will need to take account of the qualities of these new ephemera with speculative methods and processes, which might create new types, new models and new readings of our cities." Lyons [11]. The use of the image is therefore inherently conceived for an ability to instigate a new range of urban and architectural solutions resulting from the forces shaping the contemporary context more than a preoccupation to convey specific codified 'messages'. Lyon's response to both image and context is therefore dramatically different to Lynn's indexing precisely because it understands its affect as a qualitative contextual rather than physically quantitative phenomenon.

Yve Alain offers an insight into the way in which this performative framing of representation, as an issue of signification, could be approached. Of particular relevance is Bois's discussion, in *Formless: A Users Guide*, of Bataille's reading of Manet's Olympia, where both the painting's form and content create an "…uprooting, which he [Bataille] also calls a slippage, that… [reveals] Manet's "secret": the true goal of his art is to "disappoint expectation" Bois and Krauss [12]. The vital shift in the understanding of performance of representation occurs in the identification that the social conventionalising of the image's form and content also makes it implicitly susceptible to deliberate subversive slippages. The rejection of the image's role of 'naming' becomes operative because it is effectively an undoing of the conventional. As "…neither a theme, nor a substance, nor a concept…" Bois and Krauss [13]. Bataille's 'Informe' is antithetical to the attempt to create or stabilise meaning so that the instrumentality of formless resides in the capacity to operatively unsettle any ideological formations sublimated within the desire for the artefact to express figurative 'content' [14]. (Bois defines 'formless in the following way: "It is not so much a stable motif to which we can refer, a symbolizable theme, a given quality, as it is a term allowing one to operate a declassification, in the double sense of lowering and of taxonomic disorder. Nothing in and of itself, the 'formless' has only operational existence: it is a performative, like obscene words, the violence of which derives less from the semantics than from the very act of their delivery… The formless is an operation.")

In this light ARM's National Museum of Australia provides one way in which this operative undoing of figurative content might work. The project's strategic inundation and superimposition of multiple images and figures operatively resists the explication of a singular narrative. Devine's antagonism to the 'messages' within the N.M.A. can be understood as the subversion of the expectation for the building to deliver to the nation a politically sanctioned idealised image. Resonate with Carey Lyons' suggestion that public space should no longer be "…defined by the tradition of civitas, but as the medium through which the culture of mass media passes" Lyons [15], the project's tactical use of a disjunctive matrix of partial and complete two and three dimensional 'images' prises open representation to present the figurative without any unequivocal semiotic coding. As such the building acts against any paternalistic political structure by resisting its function to demonstrate the government's 'good works'. Also of import is that the generation of the design, through a mixture of image manipulation and modelling software, mediates the instrumentality of these digital tools through a socially responsive 'filter'. Issues of signification and of tool act together to establish contextual relevance.

Critically the project is more compelling where its 'images' and 'figures' are more ambiguous and unstable. Those design actions, which assume a strong semiotic correlation between image and meaning, risk marginalising the project by accusations of being too polemical. The issue extends beyond the question of whether this strategy is contextually relevant. If nothing else Devine's article demonstrates that the N.M.A.'s resistance to an easy cultural assimilation proves this point. The problem is an issue of tolerance. The capacity for these 'messages' to be rewritten should not be underestimated. This much is evident in the changes to the original central courtyard and exhibition where the more sophisticated and complex reading of history have been replaced with an idealised and less challenging narrative. This strategy reveals its weakness because of its contingency on a suitable social and political context to commission and accept the project upon completion.

The capacity for the artefact to work within a less tolerant context instead relies on another performative potential, where the separation of any correlation between image and meaning allows an alternative approach to representation. In this respect the following quote from Alejandro Zaera Polo and Farshid Moussavi's discussion the Yokohama Ferry Terminal is instructive.

"When we won the Yokohama competition, we participated in several press conferences. They asked us "what was the idea of the project?" They looked at us strangely when we began to speak of diagrams, circulation and flows. Nobody seemed to understand anything. By the time of the fifth interview we remembered Hokusai's drawings and when they asked us for the generating idea, we let it out. There was an enormous "Aaahh!" of approval in the hall. Everyone understood immediately. Depending on the moment, you have to emphasize one thing or another" Zaera-Polo and Moussavi [16].

The analogy to the iconic figure of Hokusai's wave allows the public to engage with the project without any necessity for any associated figurative narrative or symbolism. As a formal reference, it is focused on the projection of an experiential quality rather than to narrative. The folding of the figure's generative facility also adds depth and direction to the diagrammatic analysis of temporal shifts of program without the resorting to or privileging of the instrumentality of animation software.

The instructive aspect of this discussion of the Yokohama Ferry Terminal is the way in which the performative potential of the projective image revolves around the difference between the figurative and figural. Deleuze, in his account of Francis Bacon's paintings, best articulates this distinction as the figurative being representational and "… implies the relationship of an object that it is supposed to illustrate: but it also implies a relationship of an image to other images in a composite whole that assigns a specific object to each of them" Deleuze [17]. On other hand the figural is released from this necessity to represent or to possess a narrative trajectory. Isolated from narrative "…the figure becomes an Image, an Icon… (it must)… stick to the fact." Deleuze [18]. Released from the 'job' of signification, the figure becomes performative because it frustrates meaning, allowing the object's material presence to exercise affect. This is case it is very different to the normative understanding of 'affect' as some type of extenuated temporal delay allowing the presence of the 'thing' to enforce itself to one's consciousness even after the object assumes intelligible meaning. Deleuze effectively challenges this temporal conception by arguing that it is Bacon's visual strategies that short-circuit to permanently 'put off' the possibility of the figurative forming meaning. This is important because the figural is an operative undoing that resists a conception of affect as a codified set of forms deployed to solicit specific experiential outcomes.

At this point I would like to discuss the proceeding issues as they apply to my masters design research which explores the operative aspect of the image and in respect to representation and context. The project for RMIT University's (Royal Melbourne Institute of Technology University) new Janefield 'technology estate' on Melbourne's northern periphery departs from an appropriation the image of a stain that is strangely anthropomorphic. The campus form is made by, first, translating the figure into a vector line file, via Photoshop and lllustrator, and then importing it into Amapi, a three-dimensional modelling program. Once here the profile is deployed in two ways. It acts as a template for the campus 'plan' and for two different elevations, each accounting for the primary directions from which it can be viewed from ground level. The elevations are developed as anamorphic projections of oblique views taken from either side of the original image, fig. 1. These projections are then alternately spaced at regular intervals and rescaled proportionally within the 'plan' outline. A 'Gordon Surface' is extruded to generate the maximum volume of the scheme, which is then translated into architectonic form by a series of Boolean subtractions. These cuts are determined by programmatic and pragmatic requirements.

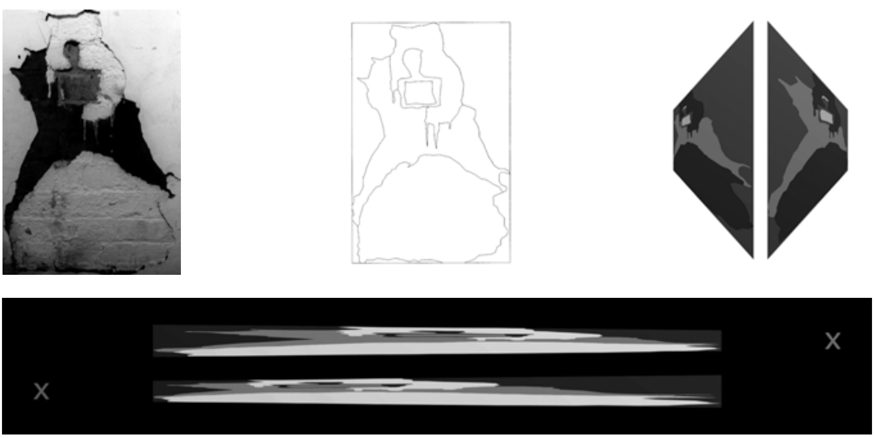

Figure 1: Translation of image to Anamorphic Projection.

The selection criterion for the figure was dictated by a lack of figurative or illustrative specificity. The figure becomes an enigmatic emblem that 'stands' for the body of the institution but can neither impart meaning nor tell its story. Without this representational stability the image works to both mark the absence of this possibility and reveal the conceit of the desire to do so. Standing in for the university, the figure acts only to locate the impossibility of satisfying this desire to re-present that which cannot actually exist. As Mark C. Taylor identifies this performance is an attempt to figure the 'unfigurable' Taylor [19]. (Mark C. Taylor argues that twentieth design culture has been preoccupied by the desire to disfigure and that modernism's abstraction and early post-modernism's excessive re-figuration participate in the same desire to capture and isolate the transcendental to make it real. Both see the relationship between signifier and the signified as absolute.)

The scheme can be seen to oscillate between the autonomy of the image and the pragmatic concerns of the project. These competing issues offer a mutual resistance preventing one concern from dominating the other. Superficially this is helpful in that both are satisfied by the requirement for pragmatically loose and mutable envelopes. The real import of this interaction, however, is that the interaction amplifies the affect of the figural reappearance at each cut, an occurrence exacerbated by the use of the figure to address a number of pragmatic concerns across a range of scales throughout the scheme. Operatively this creates an unpredictable eruption of the figure more akin to Bois and Krauss's notion of pulse, where the temporal discontinuity affects a sensation at each return. This is stark contrast to Lynn where the temporal exists only as an indexed set of numbers that are then processed to make form.

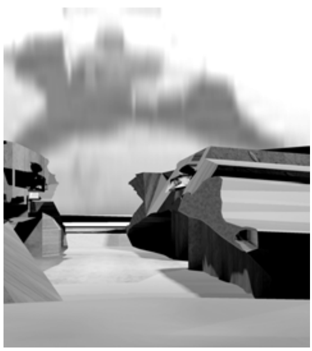

Figure 2: Experiential view.

Figure 3: Aerial view of campus.

The scheme engages with the institutional desire to represent itself. The commercial imperative to generate funding streams coupled with the desire to attract students places an onus on the 'Institution' to distinguish itself. The image, as a form of currency, imparts such prestige to its buildings, which through their iconographic strength 'advertise' the institution. To RMIT, which has strategically employed the 'trophy building' as a form of promotion, this manoeuvre becomes a strategic imperative. The image of the figure aims to impart this distinction in a context where restricted budgets compromise the ability of the university to deliver the 'trophy building'. In doing so it takes the place of more traditional demonstrations of distinctiveness achieved through the use of geometry, materiality and detail. As such the appearance of the figure within the experiential or phenomenal view, as seen in figure 2, is understood as only one of many possible views to acknowledge the strategic value of the iconic or emblematic view of the campus. In the first instance this would manifest itself in the form of the architect's speculative 'vision' of the completed master plan. As this image is subsumed by the built reality other vehicles are appropriated to ensure a public presence. This recognises both traditional modes and more contemporary virtual ‘venues’ ranging from the architectural publication and the postage stamp to new virtual ‘sites’ like Google Earth, fig. 3. For this reason the image ‘in’ the plan is as vital as those within the site.anefield scheme is conceivable only because of the existence of digital tools. These tools are significant because they allow design practice to revisit a range of architectural concerns. They also not only aid our understanding of context but they also shape it. The nature of the current political, economic and social contexts demonstrates the hazard of any withdrawal from an engagement with representation as an issue of signification or as a tool. To do so ensures that the artefacts remain ideologically trapped within a construction that it neither contests arguments of signification nor acknowledges the affect the tools of representation architecture’s artefacts. The associated privileging of a narrow range of software acts only to prematurely close the potential of the digital as well as deny the reality that all ‘drawing’ renders some part of all design processes illustrative. Conversely, the critical acknowledgement of the generative potential of representation, and by association the image, as a response to context, opens the potential of representation to re-think the making of architecture’s artefacts.

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Infoarchitecture

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Abstract

Different geometries lie behind different architectural styles.

There is now an improving alternative to the Euclidean/Cartesian geometrical environment in which the design process has developed up to now. Computational geometry has developed enough to be seriously considered as a source for new shapes for architectural objects: parametric functions and control point curves are entering the architectural design world. NURBS modelling allows the design of architecture with surfaces and volumes that could not even be thought of before the application of a computing device to their geometry.

This fact means a deep change in the epistemological charter of the whole design process itself: the geometrical immanence of a project becomes unreadable by human capabilities because the reference shapes no longer have abstract and easy-to-deal-with images (i.e. a parabola, a sphere, an ellipsoid, a cube), instead they are cryptically hidden into very complex volume aggregations that can be designed only if computational geometry is assumed into the shape definition process. Therefore, the architectural design procedure has a new step that I call "computational filtering", that allows the making of an option between the two geometrical environments. Obviously they can be mixed too, but at the moment I think this can be thought of in the same way as a standard and well-known shape-balancing procedure
Keywords: computational geometry, design methods.

1 Introduction

The opinion that studying what a digital-numerical representation of an architectural project is, is an unavoidable demand within a theoretical story about contemporary design that can be discussed, nevertheless it is outstanding that it's nature of "real topic", somehow or other, can't be denied. A topic, I think, that needs to be approached with all the instrumental means from critics and of

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abstract thought concerning all the consolidated elements. Actually, this has been made quite often and quite well, but I still see a certain lack of organic unity within this matter due to the variety and to the objective disciplinarian heterogeneity of intellectual contributes.

The didactic environment of architects and building engineers is an experiment area that should be managed with real care: it’s necessary we keep in mind that the introduction of the information technology instruments for the representation normally occurs at the same time of the first impact with architectural culture itself. This is the reason for me to think that the need for the Academies to learn to properly handle this knowledge structure can be defined as urgent.

Sometimes this urgency becomes an emergency when the spontaneous overlapping between epochal mutations (the information technology era) and didactical transformations, depending upon the computer use, which too often is as diffused as dogmatic – simply happens without even a minimal thought in design universities too.

Tomàs Maldonado in 1985 (Maldonado [1]) writes that a computer can be considered as an “intellectual prosthesis” and offers compensation to human function that lack in repetition and precision and accuracy and calculation speed abilities.

Seen from an up-to-date point of view, Maldonado’s computer, in my opinion, is a better “extension” than a prosthesis because it can’t substitute any human function but incorporates and implements new additional ones into a man skill set.

Therefore, I think that the new “digital functions” in the set do not enhance any human character but just add different chances to a generally firm environment of human capabilities. So, in the peculiar case study of the architectural project I assume that the innovative techniques should add to the traditional methods, better than being offered as alternatives.

Architects and building engineers are at the moment on very unsteady soil towards the enrichment of formal resources that the computer use can give to their design capabilities. One can produce very complete and graphically rich outputs in a surprisingly fast way, physical and economical properties of materials can be easily handled and introduced into the design procedure from the very first concept idea and the final project can be transformed quickly into the sum of its parts.

Any operation of planivolumetric re-arrangement, element substitution, re-positioning on new alignments as well as recycling of complete blocks from other external or inner sources are very accessible even from the first level of a student doing vocational training. It would be anachronistic and luddist to oppose this with a radical spirit and force students to adopt a totally manual drawing method, nonetheless I think that the best results in the use of computer graphics as an extension can be obtained if a complete and well structured knowledge of theoretical and practical geometry is given together with an adequate improvement in traditional drawing methods. Staying in the track Maldonado has shown, any technological extension (or prosthesis, it makes no difference) can work undoubtedly better if it is joined with a biologically efficient base structure.

This very important aspect tells us, with no surprise, that at present it is completely impossible to deem that the machine can substitute the hand and that the virtual cybernetic space take the place of the real cognitive thought. I think that this awareness should brightly indicate the straight and narrow path for didactics into architecture universities.

2 Representation, geometry and design

It is a well-known fact that in the territory of architecture, drawing a representation are in biunique relation with geometrical knowledge and that they cannot be considered as the more application oriented side of the *Académie-des-Beaux-Arts*-style picturing. How come then, somebody thinks that if one of the two key elements of the relationship changes the other stands still without transformations? I think we can give an account of this by simply analysing the state of things. We can legitimately think that a kind of new architectonic era has begun and that a century of new architecture is starting by means of hybrid paths through plastic arts and painting and design. Its outstanding examples are in the work of people like Koolhas, Liebeskind, Hadid, and Gehry. Concerning this last, another architect like Jean Nouvel in 2003 says "[…] his fantasy - in another era – would be curbed by almost insoluble building problems, but today's computer can make drawings and calculations and his incredible buildings can stand on. So, fantasy and inspiration can run to new brain waves […]" (Nouvel [2]).

We still have to understand if this is just the "Infoarchitecture project era" as I use to call with an explicit word, but it's a really problematic matter to stay in the course of a discussion upon the topic of the "project" without considering the mutation of the epistemological core of the topic itself.

We can't individuate it in its complete shape from our contemporary point of view but we can track down its material traces over the cultural framework that a previous archaeology has outlined (Foucault [3])

An architecture project – no matter what architecture – is given birth within the spatial thought domain with the appearance of a projective representation set, and grows to a material consistence by the action of the visual thought (Arnheim [4]). Otherwise, it goes backwards: from the idea of a projection in the field of vision the ratios among the spaces of the project are derived.

Regardless of the way a project comes out, there is an inevitable element to deal with: the language for thinking of space and vision is geometry.

We well know that no thought can exist without a language (Augé [5]) and because of this I believe that geometry is the language of the project and it's only and lonely unbreakable methodological grounding. Representation through geometry, therefore, is not an *a-posteriori* but coincides with the $\pi o \iota \varepsilon \sigma \iota \sigma$ (poiesis – primary creation) of the project itself, playing the role of the fundamental $\lambda o \gamma o \zeta$ (logos – own peculiar expression) of the whole process.

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Aristotle sees the technical thinking action as guided by the *ειδοσ* (eidos – theoretical reference) and Augé has widely shown that no thinking action can take place without a language to be built with. Therefore, the abstract model of Architecture can be expressed and even thought just within a geometrical language, while the *τεκνε* (tekné – operational skill) intervenes for the material completion of the *ειδοσ* (eidos) in the project, so that it can overcome the unavoidable defiance with the construction.

It's almost impossible to talk of project methods from a cultural point of view without dealing with transformations in the field of representation. We can't voluntarily neglect a knowledge framework that – it's a fact – is becoming the "key" for architecture lands. Michel Foucault observes how *époques* are identified by an episteme that is to be thought as an implicit and unconscious and generally anonymous rule system with – eventually – some cultural reflections concerning the rules themselves (Foucault [3]). It is just this kind of structure that defines the domain of possibility where the typical knowledge of a given era is established and works.

The passage from an episteme to another is not continuous and is not ruled by an insider logic for a progressive development and evolution, it happens by jumps, so it's not easily explainable (Foucault [3]; Thom [6]). So we cannot think of acting from inside and somehow forecast the schemes of *this* era, because "[…] the destiny of any intellectual passage is to happen without a will, without a known destination and just having control on the very close waves nearby the boat […]" (Bobbio [7]). Bringing an era's own episteme to light is a duty for what Foucault calls "archaeology" (Foucault [3]).

Then, "the speech on the already said" in architecture is a sempiternal problem: asking ourselves "how we can compare and measure architecture?" is asking the same question as "how to understand it?" and how impossible it is projecting architecture without understanding it.

Vitruvio's *De architectura libri decem* is the first try, which has arrived as far as today, to talk about architecture measuring its quantities and describing its qualities; some of those were relatives, internal to a given style, others were absolute, as parts of the cultural framework and "[…] paying the right attention, one can see that the same concepts as Vitruvio's triad (*firmitas, utilitas, venustas*) and as all the many others which followed, constitute an equal number of "measuring units", that an architect makes explicit in his designing and that critics use for pronouncing their judgements […]" (Ugo [8])

Therefore, whether the chance for a voluntary interaction with the epistemological cores of architectonic eras is not given, the chance for displaying its immanent phenomenology is in an architect's hands. In other words: architects and civil engineers can and must design. And each project is inevitably given birth inside its own cultural frame. Guarino Guarini in the first page of its treatise Architettura Civile claims that "[…] architecture has the right to correct the rules of the ancient times and to give new ones […]" (Guarini [9]) and saying that he incorporates architecture itself into an architect and – at the same time – puts himself in a position that with a game of mind we could define as foucaultian *ante litteram*, by giving the personification of the mutation will to a single man. Moreover, he resumed the vitruvian model and expressed architecture as *initium τοποσ* (topos – recurring thought) of human beings, as it's evident that no era is peopled by architects only! Men build houses that are the material phenomenology of their culture and of their historical sense.

A construction before being solid matter is a concept, because "[…] poetically men live on this earth […]" (Hölderlin [10]). "Making poetry", in the prevailing cultural frame of modernity means accomplishing tasks that imply the formulation of hypothesis, intentions, wills, projects (Heidegger [11]) and such tasks certainly and chiefly include the act of commeasuring, in other words of thinking men in a relationship with something that is absolutely "other". That brings directly to discover a hidden meaning (God) through what is uncovered (men). So, metonymically we have reached the most general and absolute among all the *initia τοποι* (initia, plural of initium, lat.; topoi, plural of topos, gr.)

Finally, even if we can't directly perceive the epistemological core of the architectural era we produce our projects and our theories on them in (neither can we have any kind of sureness that it is just what I call "infoarchitecture age") we can surely act like architects do, designing what the "spirit of times" (Hölderlin [10]) brings us to design, as even if –maybe- Architecture doesn't exist, surely Architects do (Kahn [12]) and the works of architecture are prerequisite for men.

3 Some notes about geometry

We have seen in the previous paragraph how geometry is the fundamental environment for reasoning about space and its transformations, and how no concept can exist without a formal expression, how no over-instinctual thought can be assembled without a language. (Augé [5])

So, the project for a work of architecture is a linguistic expression of an optative mood and the intention to modify the *shape* and the *matter* of a portion of *space* cannot develop in absence of the notions of shape and matter and space and of a method for organising the creative reasoning.

Shape and matter (substance) are concepts with a deep philosophical background and this makes their manipulation for other purposes quite complicated. In Descartes, extension is the only really essential property of material substance and the access to the notion of shape is strictly tied to the geometry that Descartes himself constructs (Descartes [13]).

If we accept of echoing the biunique structure of the epistemological model in a more practical instance about the structure of the geometric description systems of objects, we can remember how Kantian critique to the analytic nature of this kind of *a-priori* judgement (Kant [14]) brings us to think that the declarative proposition on ontological consistence of matter actually is a datum of a purely analytic nature, that is inherent to the exercise of direct experience. If we assume that "there is no matter without extension and no extension without matter" (Descartes [13]) we are allowed to bring the concept of extension into the fundaments of the logic domain of geometry. This, on its turn, implies the transfer into an *a-priori* judgement set for the metric topic in survey and project, elevating it to a gnosiological necessity rank even for the works of architecture, which are brought to existence within the representation ambit by means of the internal commiseration relationships among architecture elements (Ugo [15]).

If a measure – on which scale it's to be seen – is a fundamental element of a project on a theoretical level too and it is not just a repercussion of the application of a specific *τεκνε* (tekné) to its genesis, I think that taking special care to all the procedures that transform an element into its representation should be an architect's specific duty.

The notions of metric scale rate and the projective transformation functions within geometric constructions do not simply have a pragmatic role but they are real elements of the *ποιεσισ* (poiesis). They have two possible courses into an intellectual elaboration of the *πραξισ* (praxis – standard procedure): First is a logic road of the representative kind, second is mathematical, with – talking of contemporary times – a special accent upon computational aspects.

Descartes, when describing the philological line of a scientific method says: "[…] those long chains of reasons, so easy and simple, that geometers use to show their more complex demonstrations, had given me the opportunity for imagining that every thing that can fall into human knowledge are chained in the same way and that – at the only condition we refrain from taking any false thing for true and we always observe the right order for deriving the ones from the others – there is neither anything too far for being reached, nor so hidden that one cannot find it out. And I did not think too much about the starting points: as a matter of fact I already knew I had to move from the easiest and simplest to know and considering that, among all have inquired into truth in sciences, the mathematicians only have been able to find demonstrations, in other words they found evident and sure reasons, I was sure I had to start from those same truths they had found out […]" (Descartes [16]).

Descartes does not submit the archaeological knowledge problem – and it could not be otherwise – rather he desires to find the form of scientific progress and consolidate in a method-shaped structure Galileo's experimental praxis (Galileo [17]).

In Cartesian geometry, Euclidean geometry is implicitly included and the logic-deductive method based upon the axiomatic structure is still valid, enriching itself of a mathematical course which is expressed by numerical set and equations that define and analyse geometrical constructions (Reinhardt [18]).

Euclidean geometry, such as its partial Cartesian new methodological elaboration, is the set of rules that a generic material substance must and is able to follow for being a part of the existing world. Within this concept the notion of model is implicit and it's just the abstract set of the system-included objects. Therefore, the model is the reference scene for the reasoning about *res extensa*. Then well, the model is seen as the only place for a "spatial intention" which involves matter to be conceived: in other words it's the only place for the *ποιεσισ* (poiesis) of a project.

The topic of architectural composition, starting from classical times to modernism is in a close relationship with the form of geometry of its coherent knowledge frameworks. They have all been solved by means of axiomatic structures, even if, after Cartesius work and for non project-oriented applications, they can be solved through non-strictly-graphic solving procedures.

The problem of geometrical logic to apply for, or better, by means of a project can be made, had never been submitted for the reason I have just shown: there was not a system of alternative choices.

The “constructions with a ruler and a pair of compasses” that are the main topic for Euclidean geometry are the roots of any classical geometrical thinking upon architectonic proportions. The two main approaches of Greek geometry are the solving of problems of construction and of problems concerning quadrature (squaring), and both of them brought to an easy-to-see material phenomenology of geometric reasoning within classical architecture.

In the *De Architectura Libri Decem*, (Vitruvio [19]) one can find the implicit correlation between formal geometry and building geometry, as Vitruvio introduces inside the topic of project method the problem of *scenographia* (Panofsky, [20]), in other words, the problem of the projective construction of images that an eye could get looking at the architectural object if it was really built. Vitruvio gives other names to the typically Euclidean representation, such as *ichnographia* for the plan views, *othographia* for the elevation and explicitly “[…] scenographia est frontis et laterum abscendentium adumbratio ad circinique centrum omnium linearum responsus […]” (Vitruvio [19])
(Transl. by author: “[…] scenographia is the representation of a main front with also a “graphic hint” at side views, that is build by drawing together all the lines and making them converge into a small circular area” […]) .

4 Some notes on the *corpus mathematicus* of architecture

Whether the main sediment of the scientific knowledge where architecture stands is made up with geometric culture, the grains of its matter are the elements of mathematics.

Infoarchitecture is the most mathematical among all and its large amount of embedded inner numbers and equations is cryptically hidden behind the curtain of operative knowledge that allows the design of volumes and surfaces by computing machines. We know that geometry cannot subsist without a mathematical rule set, because any axiomatic system needs the dialectic form of its *ποιεσισ* (poiesis), otherwise it downsizes to simple intuition.

This *porta et clavis omnium scentiarum* (Bacon [21]) is in my opinion a straight way to architecture too, even if its straightness is actually based on the acceptance of a split path where the twin courses often cross and tie each other, as they are: from a geometrical shape to an architectural one by means of the intellectual use of the latencies and from the indistinct shape to a proper shape through the formalisation of separate space ruling laws one can obtain through computing (Papi [22]).

In the first case, geometry is the same of latency itself and of the relationship between a project and a view it can offer: so we are in need of putting some problems of the descriptive and projective kind. In the second case, the main geometrical instance stays in the computing of the material shapes and the whole problem turns into computational scope.

In both cases the speech is double, because a computational product too can be shown and seen only by projections and a latent geometry too has an algebraic side. Can we try to say that the kind of geometry is also a part of the *τεκνε*, (tekné) as far as we can trace it into the shape? Probably, this is the moment to state that there is not a single *τεκνε* (tekné) for all the architectures. Is*τεκνε* (tekné) just the way to make a work of architecture stand and stay physically joint, or from an opposite point of view, is it enriched by the methodological fringes of the project and we had better say that different *τεκναι* (teknai, plural of tekné, gr.) follow different *ειδε* (eide, plural of eidos) and that they are different by nature and result in different *ποιεσεοσ* (poiesein, plural of poiesis, gr.)

Does speaking of the "objects of the Architecture" make sense enough or it seems more likely that the "architectures of the objects" are the real topic? I think that from a different geometry which derives from a different epistemological scope and a different generative process it can't come out anything but a different architecture. An architecture that must deal with its own geometrical *vacuum* as "[…] it exists a space, which lets us presume a real space that is independent from who is experiencing it and that is already determined in its frame. Thus, more than one space is possible, there is one for each possible definition and point of view […]" (Garroni [23]).

5 The geometry of Infoarchitecture

Non-Uniform Rational B-Splines are a very flexible mathematical instrument for the construction of complex shapes in a computational scope (Rogers [24]).
They are a particular form of B-SPLINES with can we written with non necessarily rational coefficients and are in close relationship with all the Control Point Curves, starting from Béziers curves.

Their mathematical flexibility is particularly useful for all the design applications (Piegl [25]; Rogers [24]) because their shape can result by direct manipulations on the knot vector that can be conducted by means of visual interfaces with the projective space of a monitor.

Through user-friendly visual interface and easy-to-use practical parameters a designer can develop his reasoning on the shapes within the spatial thinking language and is allowed to access precision and accuracy levels which normally are reserved to the final measure check phase. The algorithms for NURBS evaluation, moreover, are reasonably fast, numerically stable and exact and if we keep in mind that NURBS are invariant functions respect affine and perspective transformations we have to consider the cultural and epistemological easiness with which the computation instrument can be integrated within the traditional geometrical knowledge framework.

In normal circumstances a project method works from general to particular, in a different way from an abstract speech or from a linguistic metonymy that are its specular reflections as in fact progress by propagation. Nevertheless geometry

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lives in the abstract thinking domain being at the same time a rule set and an evolution mechanism for the same rules: the relapses of this on the material immanence concern the reference system and because of this they cannot follow the method “from general to particular” that normally define the generative process of an architectonic design. In other words, geometry is not epistemologically compatible with his consequences on the try of modifying the space shape with a project. Geometry is inductive and deductive and formal and inferential logic and in all of these processes are concepts spreading towards rules: before a rule is given no point is internal to any geometry. Because of this I think that the relation between project and architecture happens at a rule level. Rules for Infoarchitecture include topologic approach to space. The information technology instruments we often claim as innovative come to us straight from very ancient instruments and the only really new item in the geometrical scope is the recognising of the invariant properties of any point for any condition of any plane or space. Talking of invariable properties and any deformation of a given rule we can now see how an epistemological adjustment between the abstract model of geometry and the material model of the architectonic project. Therefore, an experience in Infoarchitecure could not happen but though topologically relevant instruments with special regard to ruled planes and spaces.

6 A first test project

In my first experimental test a NURBS modeling software only has been used to define a project for a building, namely, it is a theatre with the aggregation of many other public functions, and no other traditional project method or instruments was allowed. The first logical step for an Infoarchitecture project is building a relationship between the problem and its design solution and we obtained this by means of the analysis of the expected functions of the final object and give each a “weight” that will condition the volume and the surface that will be assigned to it. We have also topologically defined a functional maximum overlap index which varies depending upon the general criteria we impose to the shape generation process.

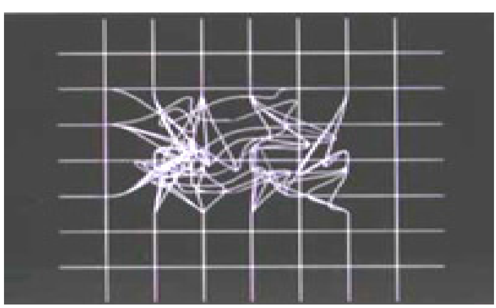

Figure 1: Plane projection of the topolgic analysis results.

As a second step we have considered the esthetical complete set of all human senses and each weight has been specifically tuned for complaining with aesthetic expectancy. This data has been geometrically transformed and projected into the model space on planes lying on the direction indicated by the analysis of human physical limits, chiefly horizontally and vertically, but without forgetting the connections, and with a “weight quote” assigned to sloped paths.

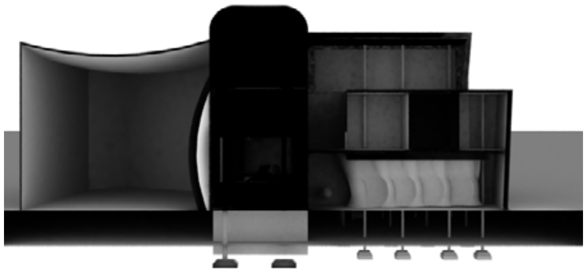

Figure 2: Volumes and surfaces interaction.

Finally, the shape projected on a reference plane had then transformed spatially towards a volumetric consistence with the total respect of topological rule concerning each element. The volumes have been physically verified and developed with regards to matter and texture.

Figure 3: The final architecture of the “Inforchitectural Public Theatre”.

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Understanding qualitative drivers in distance collaboration for architectural services

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Abstract

Enhanced global connectivity, networks' capacity to carry data, and increases in transmission speed already affect the way architectural practices work. With computer-assisted drafting (CAD) equipment now used by the overwhelming majority of architectural offices globally, electronic transfer of drawings is on the rise, followed by opportunities to benefit from the economic advantage of digital technologies by setting up remote links. Researchers in areas such as the media, software engineering, accounting, and light manufacturing have examined the industrial, cultural and regional development underpinnings of such phenomena. By contrast, very few analyses exist in architecture that link technological opportunities to social transformations, and technical skills to market development. Our research responds to this challenge by investigating qualitative differences in the performance of distant actors, and aims to determine whether these differences can be related to environmental characteristics.
Keywords: outsourcing, architectural firms, drafting services.

1 Introduction

Enhanced global connectivity, networks' capacity to carry data, and increases in transmission speed already affect the way architectural practices work. With computer-assisted drafting (CAD) equipment now used by the overwhelming majority of architectural offices globally, electronic transfer of drawings is on the rise, followed by opportunities to benefit from the economic advantage of digital technologies by setting up remote links [1, 2]. Researchers in areas such as the media, software engineering, accounting, and light manufacturing have

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examined the industrial, cultural and regional development underpinnings of such phenomena [3, 4]. By contrast, very few analyses exist in architecture that link technological opportunities to social transformations, and technical skills to market development. Our research responds to this challenge by investigating qualitative differences in the performance of distant actors, and aims to determine whether these differences can be related to environmental characteristics.

The division of labour between design and technical production has been a perennial aspect of architectural project organization. The acceptance of computer-assisted drafting equipment and the sophistication of electronic communication has facilitated this division of production globally. However, little information beyond the anecdotal is available about the qualitative performances of offshore architectural production. Unless one has participated in such ventures, it is difficult to assess the potential and viability of geographically distant outsourcing.

Supported by an Australian Research Council grant in 2005, a research program was established, which proposed a series of controlled documentation collaborations between seven Melbourne-based architectural offices and four types of service documentation sub-contractors. The project seeks to: 1) identify potential difficulties faced in establishing collaborative linkages; 2) identify factors that impact on collaboration viability; 3) identify indicators for the demonstration of skills within three tacit practice arenas. These arenas being: vocational (ability to simply act as a drafting agent, by translating information into construction drawing formats), professional (understanding and supporting the design intent and implied design language, tracking down possible inconsistencies; and adding or correcting incomplete information) and socio-cultural (regulatory requirements, codes of practice, technical traditions that influence the selection of details; and project procurement practices and the structure of documents).

Through this process, we hope to develop an inclusive conceptual scaffold that allows the successful parameters of digitally supported distant collaborations to be characterized, and their likely impact on forms of architectural practice to be weighed up [5]. The aim is to articulate the conditions that should be satisfied for Australian architectural establishments to outsource their work, and to determine whether or not the different types of firms involved in the market of digital collaborations at the moment have the technical capacity and operational synergies for effective alliances. This will lead to an evaluation of the industrial potential of distant collaboration between architectural providers, and the assessment of the likelihood that such practice will develop into a fully-fledged mode of service delivery [6].

This paper reports the results from the initial stages of our research experiments, data collection and preliminary findings arising from a pilot project.

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2 Project structure

Seven Melbourne-based firms were chosen to reflect the profile of the local profession in terms of professional markets, practice size and work focus. In consultation with each practice a project was chosen that typified the practice's working platforms. These projects form the basis of a series of investigations that will compare the performance of four types of documentation service providers:

- Australian firms specializing in contract documentation, thereby reflecting local market labour division;
- Web-based firms; set-up to work remotely and take advantage of technological opportunities;
- Indian based professional firms; with similar historical roots but different socio-economic and environmental conditions;
- South-East Asian firms, with a staff profile in Australian education and professional practice.

The proposed brief is for the service providers to produce a sample set of seven different construction drawings derived from the schematic and design development drawings of a completed project of the Melbourne-based practice. The task is to interpret and convert schematic drawings and preliminary information into a potential construction drawing set. The sample series of documentation is representative of location, assembly and component drawing arrays that engage with the project at different representative scales.

The first stage of the research program has been to establish a pilot project to understand and test the operative conditions that would need to be confronted and resolved prior to the full project study. For the pilot it was decided to use one of the most common project types of Australian architectural practice – the single family house. The project embedded a series of technical tests and design resolution tasks as the building is a modernist design unit, placed at the high-end of the domestic market incorporating quasi-industrial materials and construction systems (e.g. concrete and commercial aluminum window sections).

The Australian architectural practice had produced a higher than average amount of highly resolved construction documents, many of which were relational in nature to fully explain the integration of services, finishes and joinery units. Location drawings were set up as a series of layers effectively trade sequencing structure, services and finishes in order to minimize the potential for positional errors due to the use of concrete as the structural and aesthetic generator of the architecture. In addition, resolution of structural engineering, regulatory controls, services incorporation and building performance issues necessitated careful detailing in order to ensure the fine tolerances of finish demanded by a building design of deceptively simple but precise lines. In fact, it was during the design documentation that the architectural practice invested most of its skilled-labour.

The interest therefore lay in testing the ability of a collaborative documentation partner to coalesce with this working method. For this reason, the proposed documentation drawing test included four plan drawings, three of which represented the building at different levels; one additional plan which indicated the layering methodology dividing structure and finish; one critical representational elevation and section drawing; one drawing of vertical construction details linked back to the section and one drawing of vertical and horizontal window details which were crucial to achieve the design aesthetic proposed. The selection of these documents was deliberate, to expose:

- The understanding of the design intent and its consistency of interpretation through various modes of representation;
- The resolution of technical issues and the consideration of these issues through the different levels of the building;
- The familiarity with and understanding of Australian building regulatory regimes;
- The ability to deal with local codes of practice by including a specific request for the proposal and technical resolution of a drainage layout in compliance with an Australian Standard industry code. The layout required consideration for its integration with the building aesthetic and the implied condition for the concealment of all services and forethought of potential construction conflicts with the design intent;
- The ability to understand, interpret and communicate proprietary systems, and resolve these within the design schema.

The challenge, here, was to understand and represent subtle variations in the configuration of each system vis-à-vis its position in space and within the building whilst supporting both semantic and performance value of the solution designed by the architectural practice. It also afforded the ability to gauge the response to the firm's specific language decisions (i.e. prescriptive technology), interpretation of regulatory requirements (i.e. normative technology) and understanding of local traditions (i.e. conventional technology).

To facilitate the production of these drawings a project information package was compiled that consisted of:

- a series of preliminary generating design sketches for the project;
- a series of images that were used as reference sources for the design intent;
- a cad file site survey drawing, defining property boundaries and site levels;
- a pdf set of regulatory approved town planning drawings;
- a complete set of 'Autocad' design development drawings; and which would form the cad drawing basis for the proposed documentation set;
- a series of construction detail sketches to communicate the key assembly components;
- a description of the principal construction elements and a list of proprietary systems with limited accompanying trade literature;
- a cad file set-up of the architectural practice's documentation protocols (layer and line types, title sheet set-up);

- a pdf copy of a complete set of construction documentation drawings from another project, which would be used to define the architectural practice's documentation communication strategies;
- a set of instructions on the seven required sample drawing set to be produced with a specific requirement for a proposal for a roof drainage design in accordance with a particular Australian code of practice, fig 2;
- a list of the proposed total construction drawing set for the project numbering seventy-one drawings.

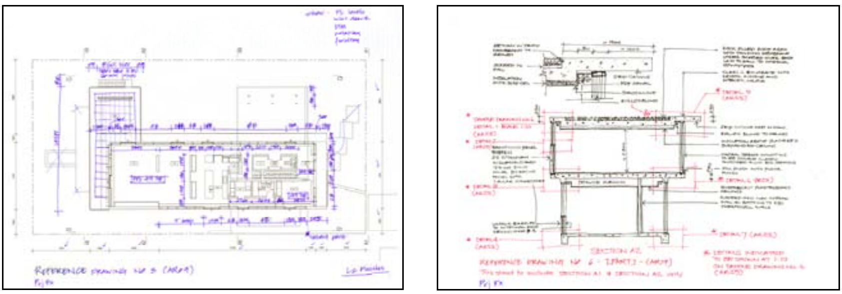

Figure 1: Sample of sketch and design development drawings provided. (Source: Authors, based on the Australian practice's drawings.)

It was decided to direct the pilot project to a limited number web-based firms first, in order to determine the potential take-up rate, anticipated cost, market condition and operational procedures. In effect, what would happen if one blindly went out to generically test the waters of web-based documentation service providers?

3 Project process

Web-based firms were sourced from their exposure in print media, through internet based search engines and by referral. The final selection of firms was based on the web-site descriptions of their service capabilities, practice capacity, experience with off-shore alliancing and English language capabilities. Following this process, a list of eighteen firms was collated. Of these firms: ten identified their geographic base as being in India, three in the Philippines, two in the United States, with one each from Mexico, Botswana and the United Kingdom.

An off-shore electronic website was established and through this facility each firm was forwarded an electronic mail invitation to participate in a pilot test, to investigate the suitability of remote documentation services to a selection of Australian architectural practices.

The firms were invited to register their interest in providing such services, with a request to forward information on firm profile, contact details, references, payment conditions, quality assurance procedures and confidentiality arrangements. The invitation outlined that through a secure server the project information package was available with a request to translate the information into construction documents in Autocad Dwg format and to price, on the basis of the scope of work identified, the production of the limited set of drawings as well as the entire documentation package and to indicate the turnover time anticipated for both the test and the complete documentation package.

Of the eighteen firms five responded immediately and downloaded the information package, three were based in India, one from Botswana and one from the Philippines. One of the Indian firms proposed working on the project on the basis of hourly rates that were approximately 26% of the Melbourne practice; however, they did not proceed beyond this communication. Another Indian based firm (Firm 1) and the Philippines firm (Firm 2) proceeded further by providing the requested service provider information and followed with engagement terms.

Firm 1 identified that their client base was primarily in the USA, with some clients from the UK and Germany. They had not worked with an Australian client and were not familiar with Australian regulatory frameworks. Their core services were in the transference of conceptual sketches into base CAD drawings and the production of CD sets from DD drawings for a range of project types including residential, corporate, education and retail work. They presented ISO 9001-2000 certification as evidence of their quality assurance system. No information on staff numbers or capacity were provided, except a brief profile of six unnamed personnel, five of whom held architectural degrees from Indian institutions with one identified as a consulting architect with US practice experience.

Firm 2 identified that their client group was primarily Philippine based, although they had current projects in California and had completed projects in Shanghai. They lacked experience with Australian regulatory frameworks, with core services being in full scope construction documentation and presentation rendering. No information was provided on their quality assurance procedures. They were a small office, identifying by name the two architect principals and seven staff members, one of whom is an architect.

Fee proposals were such that the quote from Firm 2 was 47% of Firm 1. Both requested a down-payment, with Firm 1 requiring an advance of 50% of the fee up-front prior to proceeding. Both firms were engaged to participate in the pilot exercise.

Both firms responded with the complete set of drawings within twelve days. During this period Firm 1 issued an intermediary set for review with minimal queries and Firm 2 issued two intermediary sets with a number of queries, although not extensive quite specific in their content. Firm 1 requested payment to cover the costs of purchasing the Australian code that the project instructions required.

The drawing sets provided indicated that neither firm had difficulty in setting up the required cad standards and that layering protocols and documentation transfer were not a point of issue. Neither firm established clear and well defined project management protocols. The process of managing project communication and requests for information were loose and necessitated the implementation of a system to control these aspects of project delivery.

Neither firm proposed the development of the documentation beyond the minimal requirements of the tasks set. Detailed resolution of important design and construction aspects were cursory and unresolved. Significantly, there were important construction details dictated by the design that were not picked up, these included issues dealing with waterproofing, provision for movement and the treatment of finishes.

Two examples are presented as indicators of the vocational, professional and socio-cultural evaluative categories to the pilot responses. The first is a selected overview of the vertical sectional assembly detail drawing, fig. 2; the second being the response to a proposal for a roof drainage layout.

Vocational evaluation centred on the ability of the firm to transfer information into construction drawing notational formats. Firm 1 had a greater number of inaccuracies such as missing lines, lack of drawing legibility with consideration to drawing formatting, poor cross-referencing, as well as notational and dimensional inaccuracies.

Professional evaluation centred on understanding and supporting the design intent and implied design language. This is best exemplified in both firms response to the request to propose a roof drainage layout in compliance with an Australian standard code of practice. Neither firm outlined how they interpreted the stipulated code requirements for roof drainage, with Firm 2 initially proposing a drainage system that did not account for the construction system or important design imperatives and issued drawings indicating exposed downpipes along a visually prominent fully glazed façade. They, however, responded to a request for the concealment of these drainage outlets by a well resolved solution and provided additional explanatory relational drawings to indicate how the system was placed vertically through the building. Firm 1 proposed a system that potentially altered one of the important design intents of minimising the concrete roof edge profile. The proposal did not account for structure, embedding vertical drainage within precast concrete wall panels and failed to facilitate the required ceiling levels demanded by the design aesthetic.

Socio-cultural evaluations embraced technical traditions, regulatory requirements and the structuring of the documents. Both firms did not display high levels of engagement with these issues. Detail drawing sheet layouts were confusing and counter to the implied approach suggested through sketch information. Firm 1 proposed glazing profiles that were counter to specifications, with Firm 2 relying on information requests rather than sourcing available technical material. Firm 1 displayed poor understanding of proprietary systems and documented information that generated internal conflicts within their own drawings.

Both firms displayed attributes in drawing conversion capacity but lacked proficiency at tasks that required high order capacity in vocational, professional and socio-cultural considerations. The process also suggested that the design development drawings were in fact already highly resolved and therefore major errors and discrepancies were not overt.

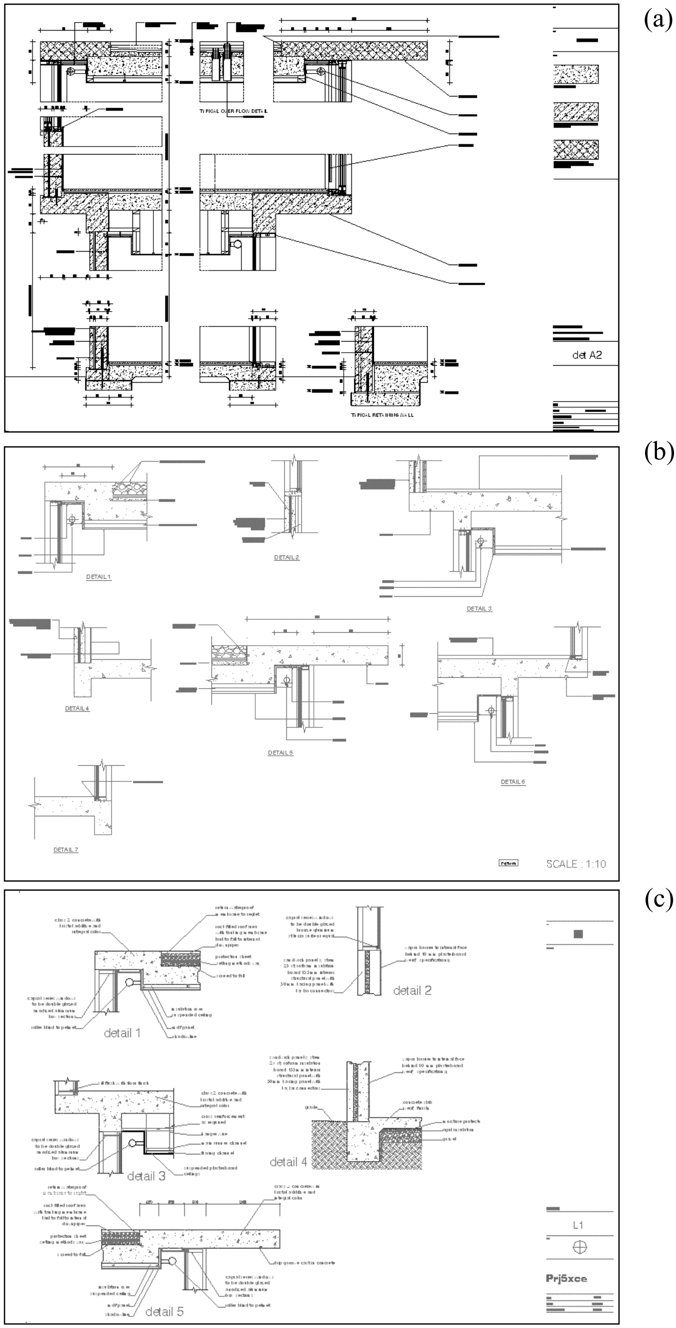

Figure 2: Detail drawing sheet. (a) Actual project (Source: Australian based practice); (b) Firm 1 (Source: Commissioned by authors); (c) Firm 2 (Source: Commissioned by authors).

4 Discussion

Although the pilot study proved to be a limited sample it still provided the opportunity for a series of speculations to be proposed and exposed a number of issues that will inform the next phase of the investigation.

4.1 Low response rate

One may speculate as to why the take-up rate was so low with only 28% of invitees responding and only 11% continuing to proceed to participate in the test project. It may well be that the firms were not yet committed or geared to offshore transactions. The cost of establishing a web-based profile is relatively low, with no risk attached in creating a web profile and using it to gauge market interest. There was also no ability to gauge whether the firms were already operating or still operating in the form presented, nor could it be determined how long they had been operating in the way they had presented themselves on the web.

Was there was a mismatch between the advertised capabilities and the proposed task? Were the firms geared towards conventional drafting or presentation packaging as against design and technical resolution? Did the task require a greater level of interpretive expertise or a higher level of technical sophistication beyond the in-house capacity of the firm and therefore the project was not of commercial interest? Did the test in requiring information on experience with Australian regulatory frameworks preclude those firms who lacked such experience and the entrepreneurial will to pursue the opportunity presented? Was it simply as one respondent advised that they were just “too busy”?

The form of approach may also have led to a low acceptance rate, as the offer was presented in terms of a brokerage arrangement. The positioning of an intermediary removed the opportunity to enter into a direct commercial relationship with the potential actual client and may have lessened interest in proceeding to engage with the pilot test as proposed. The firms may already have established markets and are less interested or have no need to go through intermediate steps.

Such speculations and questions demonstrate the need for research into outsourcing to include the operative conditions that prevail from the service provider perspective. It highlights the difficulty in identifying appropriate service partners. In order to cultivate particular relationships there is a risk in adopting a generic approach and much greater specificity is required. Further stages of the research will include investigating the performance of web-based service providers where face-to-face contact and preliminary capacity reviews have been undertaken.

4.2 Pre-planning and project management procedures

The study also made clear that offshore outsourcing requires considerable pre-planning and the identification and formalization of the required processes in advance of an approach to potential service providers. Although many of the web-site descriptions suggested that communication and project management procedures and protocols were in-place this was not found to be the case when information transference commenced. This necessitated the implementation of communication and document protocols to manage the process and outsourcing relationship.

4.3 Upskilling

The pilot also raised the question of the need for upskilling of service providers in local regulatory conditions. The need for a regulatory and trade referencing library or on-line subscriptions to such services where available is an important aspect that requires consideration in how the process is managed with a service provider. It is difficult to gauge the reality of a firm's capacity in this regard and the progressive costs that may accumulate need to be factored into the project. Should a local practice establish an operating budget to be allocated to upskilling service partners and how is the associated risk managed?

4.4 Quality assurance and design resolution

For collaborations to be effective the pilot has indicated that the quality of service provider output is dependant on the quality of the information provided. The use of a highly resolved design development set of drawings in this study has shown the benefits that arise in lessening miscommunication and misunderstanding of design intent, however, these are not obviated in the detailing aspects of the project. It also suggests that significant portions of the design resolution need to be shifted from the construction documentation stage to the design development stage and in the initial relationship with an offshore service provider these need to be controlled in-house. The production of drawings with key review and witness points permits a practice to use the service provider as an important component of their quality assurance system as it forces documentation review, which may not occur in-house due to the convenience of over-the-desk communication. It also highlights the diligence requirements that such arrangements produce, due to the fact that liability cannot be divested to an offshore agency operating with very different legislative controls and the cost associated in pursuing such partners. However, it also indicates that the potential cost differential allows one to become aware of detailed design issues and spend more time developing and resolving the design or pursuing alternate design options.

4.5 Price as a service indicator

What has also been alluded to in the study is that cost is not necessarily an indicator of service quality. In this limited study of the two study participants it was the one who was 47% cheaper that raised more information requests, picked up discrepancies between design development drawings and produced a higher standard of documentation output.

5 Conclusion

The pilot study, though limited in scope still exposed issues that suggest that any decision or evaluation of production outsourcing requires a more holistic approach, linked to determinants other than simply cost. In particular, it has shown that outsourcing is an important exercise for any firm; presenting opportunities but also problems that are not only technical in nature. It forces a rigorous introspective view of one's procedures and methods of work. Each firm will have to organize the work differently, because the elements critical to the practice will change. It is intrinsically linked to the design and production methods of the commissioning practice and the capacity of the service provider to understand and work with these operating methods. Offshore documentation partners cannot be viewed as generic efficient service providers, because the work itself is not generically developed. Distant alliances do represent a different model of project organization. For these alliances to be successful they require the identification of specific collaboration profiles which do not necessarily represent a different model of practice. The next phase of our research hopes to provide some further insights and benchmarks for these collaboration profiles.

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Narrative and the space of digital architecture: implementing interdisciplinary storytelling in the design of interactive digital space

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Abstract

This abstract and the resulting paper explore the ideas of narrative and context as generative tools in the digital design process. This is the initial premise of an interdisciplinary graduate seminar taught at the University of Florida between the Schools of Architecture, Fine Arts, and Computer Science and Engineering. The resulting design narratives will be discussed and evaluated. The different types of narrative – conceptual, plot based, etc. – will be examined and new types of interactivity will be proposed and tested.
Keywords: digital modelling, narrative, design education, animation, virtual space.

1 Introduction

"Door, window, stair… once upon a time…" The power of storytelling set in stone and steel is one of the most powerful attributes of architecture. Architecture is the ultimate portrayal of a narrative. It is physical, interactive, and permanent. It is a real time immersive experience that can be enjoyed by multiple readers simultaneously. It is a story. Storytelling is not typically thought of as the role of the architect, but truth be told, the ability to guide and shape one's set of experiences through design is arguably the most impacting of narrative devices. Architecture tells the tale of the values or identity of its patrons and place, knitting together an understanding of its particular situation within a set of contexts and the spatial language of inhabitation. How one is choreographed upon entry of a designed environment and led through as though a character in a carefully scripted plot is the ability of architecture to tell a tale, moreover an interactive tale.

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The word *narrate* stems from the Latin *narrare*, which in turn stems from the Indo-European *gnarus* which means "to know." The first implication of this root is that to narrate one must possess knowledge of something. The second implication is that the act of narration can be a passive act of possessing knowledge and allowing for it to be uncovered; that is the knowledge or lesson to be shared can be availed to the reader in a non-active way. The term has come to mean the active conveyance of a story or information by a narrator: one who tells a story or gives an account of something – a raconteur. What is explicit though in the etymology of the term is that there is a relationship between the transmitter of conveyance and its receiver. There must be an engagement of some sort that bridges the space between them so that the story can be shared. In doing so, the space of the narrative is simultaneously occupied by both. In oral traditions, this is often accomplished through song as the narrative vehicle.

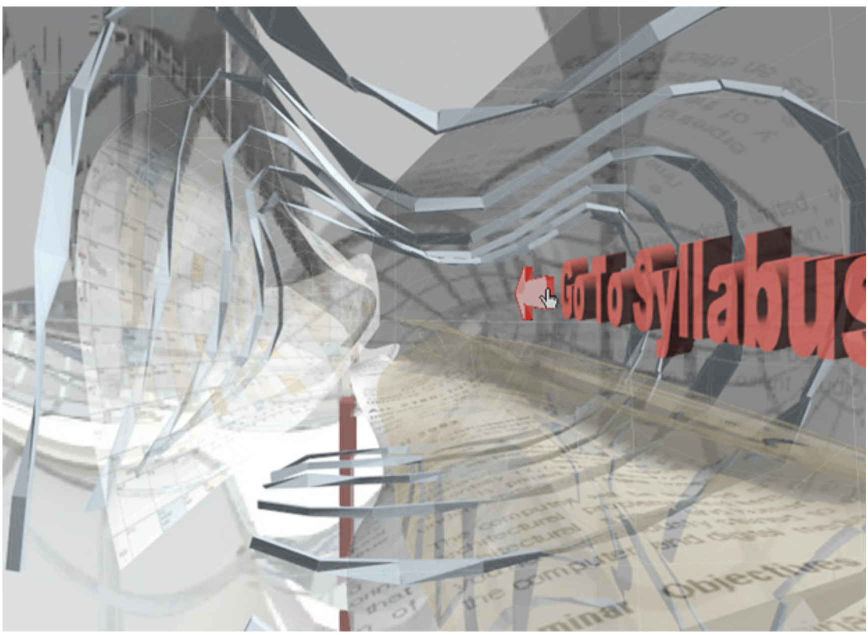

Figure 1: Virtual narrative space serving as the webspace for a digital architecture class. Assignments, syllabus, and project gallery are interactive navigated using VRML and QTVR.

2 Narrative typology

There are many possible types of narratives ranging from the most mundane newscast to the most involved epic poem. In an attempt to clarify the intentions of fine arts and architecture students at the University of Florida who are developing spatial narratives, possible narrative schemas are categorized into the following list. By defining the narrative typology of how an idea can best be presented, one can craft the narrative more accurately. The following list is not intended to be all-inclusive.

2.1.1 Scenario: action based

The most widely familiar narrative is the plot or action-based type. The story unfolds through the actions of a protagonist (e.g. an actor or character in a book) or through choices made by the user, who assumes the first-person role of protagonist (i.e. videogame). The particular perspective offered is that seen through the eyes of the protagonist, or in the case of storytelling, it is typically through the eyes of the narrator that may take on a third-person perspective.

2.1.2 Allegorical: metaphorical

A particular idea can be conveyed in the form of a story, or an allegory in which the meaning behind the words is not as direct as with a plot-driven narrative. There is a concept that can be explored and expressed by virtue of the quality of the descriptions placed into the narrative structure.

2.1.3 Artistic: impressionistic

The artistic narrative expends its energy in description alone. There is a perceptual lens through which the reader experiences the imagery described by the narrative vehicle. Interpretation of the substance communicated is required by the reader to make sense of it.

2.1.4 Informative: instructive

Knowledge communicated in a straight forward manner for the purpose of instructing others can be categorized as informative or instructive. The information ticker visible on CNN broadcasts, or the New York Stock Exchange ticker does just this without any sort of editorial overlay. The NYSE stocks page in the business section of most newspapers follows this same example, which is to deliver the prices as clearly and concisely as possible.

2.1.5 Spiritual: value-based

The Old Testament of the Judeo-Christian faith conveys a set of lessons about morality, faith, and honesty in the form of historical accounts of early human history. Without discussing the specifics of the several books that comprise the Old Testament, it demonstrates the overlay of spiritual attitudes on otherwise straightforward scenario-based narrative. The New Oxford Annotated Bible published in 1962 includes a subtext at the bottom of each page that recounts the information of the original King James translation in a clear, factual manner. It almost reads as a history text without the valuative and spiritual overlay, and is an interesting comparison to the original text above. Many non-religious childhood stories present at the end the phrase “and the moral of the story is…” demonstrating that there is a lesson to be learned by reading or listening to the story. This is the real narrative. The scenarios that serve as the vehicle to share this narrative are secondary to the message that is intended to educate.

3 Narrative in architecture

Narrative instils meaning. Architecture tells tales that we move through as characters. This spatial tradition is less fluid than an oral tradition, but is even more powerful because all of the senses are engaged as one is moved and guided through space. Often students get caught up in the latest theory or conceptual jargon (myself of course very guilty of this) and forget the simple joy of shaping ones spatial experience via an architectural journey. The sequence of spaces encountered and the quality of those spaces tells a tale the way a filmmaker shapes ones understanding of a narrative frame for frame. According to filmmaker turned architect Rem Koolhaus "there is surprisingly little difference between one activity and the other… I think the art of the scriptwriter is to conceive sequences of episodes which build suspense and a chain of events… the largest part of my work is montage… spatial montage" [1].

All that is placed within the design of a space speaks to the intentions, the desires, the values of the designer; or at least it can and perhaps should represent the idiomatic qualities of the designer, client, or both. The way that light is sculpted, the manner in which the space is entered and experienced, the materials that make up the enclosure and its contents all have the potential to evoke meaning far beyond just utility. The spirit of the place and time is conveyed by virtue of the choice of materials available, and the technology used to erect it. The regional climatic needs can be represented in the size and placement of apertures, the threshold condition upon entering the space, and the shape and height of ceiling and walls. Though the advent of electronic climate control systems, the mass production of building materials, and the global systemization of building practices all diminish the potential for these phenomenological factors to be quietly incorporated into the design of most spaces, the possibility is still there.

Architecture forms a series of possibilities that can be explored by the user/reader. The plot is played out by those who enter and allow their destinies to be dictated by the architectural syntax: walls, doors, stairs, windows, etc. This syntax structures the architectural journey through space and time, and presents the reader with a series of decisions. Each decision helps the plot – the narrative – to unfold and develop accumulatively. The story becomes entirely interactive by virtue of the sometimes-unforeseen outcome of the decisions made while navigating through the architectural journey. The architecture can use other narrative tools in its roll as storyteller such as foreshadowing, flashback, and suspension of disbelief.

4 What is virtual architecture

Virtual architecture is defined as the process of ethical and appropriate designing in cyberspace in a fashion specific to its context. The appropriateness of the design is important as the design determinants in this virtual world devoid of worldly materiality, gravity, and natural phenomena (i.e. rain and wind) call for a different set of principles for the creation of space. There is no need for architectural necessities such as floors, roofs, and stairs, so the design syntax is quite different. Representations of buildings or physical constructions have no place in this world, and are as such not ethical to the context of cyberspace.

"Virtual spaces that mimic real buildings, as in a virtual Barcelona Pavilion or Palace of the Soviets, call to mind the difference between Normal Rockwell and Mark Rothko. Both are painters, yes, but Rockwell the realist raised the bar on illustration, while Rothko, the abstractionist, perfected canvases that profoundly influence the way we see the world. Obviously, I believe that virtual space has to be about the latter achievement and not a mere reflection of our world as we know it; it's a deep study of possibilities and the unknown" [2].

In the beginning, the digital interface was strictly one-dimensionally text-based. Prior to the invention of the Graphic User Interface (GUI), data was entered into the computer via punch cards. This evolved into a text-based system that used a keyboard, and was the standard for decades until the early 1980s when Xerox developed a new system that employed a mouse to navigate across a two-dimensional screen replete with graphical icons. This is still the standard used nearly two decades later. Of course, the spatiality of the interface will always continue to evolve. Microsoft has developed and is currently testing a three-dimensional interface, where the lexicon of flat icons and windows has segued into three-dimensional objects and spaces. What logically follows is the venture into a four-dimensional interface, where space is constructed with moving images. Suffice it to say that there is a concerted effort to emulate qualities of the physical world in the digital context. The state of the art in digital interfaces is three-dimensional, so it should follow that the context of virtual environmental design is three-dimensional. Gradually more and more websites will become webspaces as the advantages of a less-flat delivery environment become more apparent.

5 The narrative and virtual architecture

Part of the challenge of developing narrative virtual spaces is that there has been a shift towards more of an image-based tradition from one that has traditionally been oral. Technological shifts in how we communicate has aided in this demise of orally transmitted knowledge, as have changes in cultural values, economical apparatuses, and building traditions. More and more, we do not place as high of a value on narrative as a concept as we once did, choosing instead more immediate means of communicating and being entertained such as the internet, news broadcasts with simultaneous streaming tickers of current events, and reality television. Obviously the time of families gathering around the radio for the nightly broadcast or telling stories around the fire are gone, so in avoiding a nostalgic retreat, we shall suffice it to say that the attention span of the emerging global community is growing shorter by the second and with this decline in communicative engagement, the way in which we regard other humankind is suffering.

Architecture involves physicality in its engagement of the viewer, what then happens to the narrative style and syntax to tell a story if the architecture is purely digital? Since three-dimensional modelling environments became the norm in the practice of architecture, speculation has occurred about the ability to design virtual realms that are not of the corporeal world, but of a world of pure data. The context of course is vastly different as is the type of architectural response to it. The engagement of the body is quite limited in most cases to these senses of sight and hearing, so in order for the architect to narrate with design, the architecture of walls, doors, and floors will not be adequate because the body will not inhabit this digital environment. So what is the resulting architectural language needed to convey the same magnitude of storytelling?

Day to day GUI use involves vast quantities of image and text information to be sifted through in order to acquire knowledge. This is the current reality of the World Wide Web. At some point a decision had to have been made during the creation and evolution of the web to make it more image based as in print media rather than spatial as in the physical world. Even news broadcasts have started to move in this flattened direction as more and more textual and image-based tickers of information are scrolled across the screen, even at times obscuring the view of the newscaster sitting space broadcasting the information to us. Little argument could be made to the postulate that human kind is moving away from an oral (interactive and spatial) based tradition of communication to one that is based primarily in the immediacy of an image (fixed and sedentary).

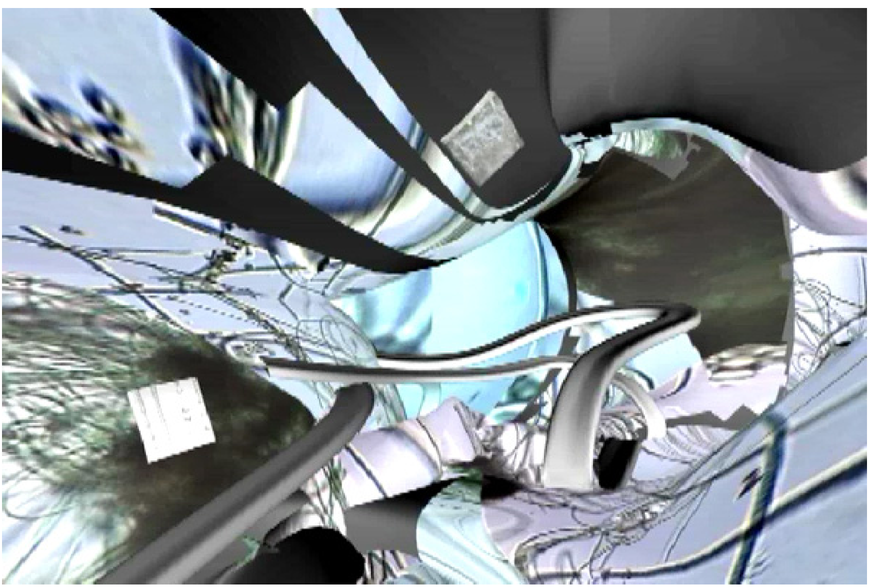

Figure 2: Digital narrative environment exploring the phenomenological experience of water by Eric Peterson and Marie Marberg.

5.1 Narrative structure in the virtual realm

There are five primary layers to the virtual narrative space, each necessary for the first-person portrayal of the intended spatial experience. Each of these works in concert with the others to produce an immersive experience for the user that captivates the imagination and titillates the senses. This can be seen as similar to the requisite components of theatre that include the set, the lighting, the make up, the costumes, and the script, all of which support the actors who play out their parts.

In the cinematic traditions, these dramatic determinants have an additional set of layers that help to shape the overall perception of the film. This governs the intermediary vehicle for the user to be engaged by the narrative: the camera. Film is conceived to shape the environment of the narrative for the space of the camera. Instead of the audience member being able to have perceptions of the action on stage specific to the location of the seat, by shaping the story for the space of the camera each audience member receives a nearly identical portrayal of the narrative. The subtlies of camera angle, camera movement, focal length and depth of field all shape the perception of the piece. In addition, film type and speed also shape the final collection of images. Various film types have idiomatic colorations and qualities that can be used to create moods and overall thematic content in the piece beyond what is available through the actors and other primary elements of the narrative. In recent years, post-production offers a new array of layers to the narrative structure. Special effects and computer generated wizardry add a new array of layers to convince us that the action on the screen is "real" and that we should feel engaged in the narrative.

For the purposes of clarity, assume that there are five layers that constitute the perception of a virtual narrative. These work together to create an environment of engagement and interplay. There is some overlap between some of these layers, but each does posses its own independent specificity when crafting the narrative environment. Each can individually sway the perception of the space in ways that the other cannot, but do all coalesce in a gestalt not otherwise possible.

5.1.1 Backstory

The "backstory" is essentially the untold story of why the encountered spaces are the way that they are. A lot of the fundamental meaning inherent to the virtual space can be described in this manner. It is also helpful in describing why the user is "there" in the first place. Myst, the widely popular and influential game operates almost entirely within the backstory, supporting it with the design of the environment. The user finds oneself in an environment with no immediately-known purpose, and has to piece together the story through subtle clues found within. Only over time and experience is the backstory revealed so that action can be taken to resolve issues that it created.

5.1.2 Narrative overlay

The "overlay" is the particular lens through which the perception of the narrative space is portrayed. This is the general attitude about or the take on the circumstances that make up the space, and adds a certain bend to the narrative. An example could be an environment that is devised to be a spatial journey into and through a mandala, a spiritual meditative painting. The overlay is that the journey is transcendental and recalls a hallucinogenic trip. This fact, once realized, shapes the reaction of the user to the environment that is encountered. It helps define the logic, perhaps hidden, governing the design of the virtual space.

Figure 3: Digital narrative environment based on the writing of French scholar Gaston Bachelard by Sean Williams and Paul Girello.

5.1.3 Environment

The "environment" is of course the perhaps most defining element of the narrative. The spaces in which the story unfolds have to be designed in such a way that the other layers do not have to be too heavily wrought to carry the virtues and action of the navigation. This is the architecture of the space; that is to say the specific relationships between various spatial experiences and the qualitative nature of each. One must decide carefully the overall language of the spaces and how is it tied into the structure of the narrative. How one produced the lighting and materials of the environment sets the mood and tone of the story.

5.1.4 Navigation

The "navigation" typology governs how the experiences are laid out for the user. Whether one is allowed to move freely throughout the designed environment or is contained within a certain trajectory strongly shapes the perception of the place and that within. There is a big difference between moving through a virtual space in the first-person (i.e. viewing it from the vantage point of an inhabitant) and finding one's way through in the third-person (i.e. by moving a character through from outside the environment as in a plan).

Examine the difference between “exploring” and “navigating” space. The former implies to set out on a journey to discover new things, to venture into the uncharted waters of the unknown. The latter implies to find one’s way through charted waters, to use direction-finding cues found along the journey to aid in arriving at one’s intended destination. Similar terms that in the computer vernacular have become one in the same, although the essence of what each term means is quite the opposite of the other. Yes, each means to set out on a journey, but one relies on the records of those who have gone first. As ubiquitous as these terms are in our day to day lives surfing the net or searching for data, each appeals to a different mindset for how space is to be transversed. In the digital realm, if one were to embrace the terminology, the way in which datasets are made available to the user/reader would be quite different.

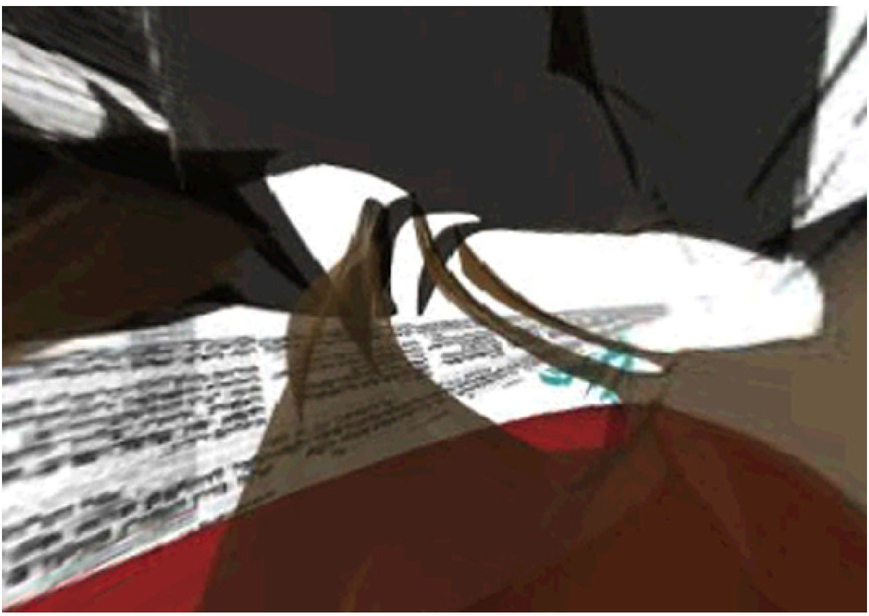

Figure 4: Digital narrative environment based on the seven days of creation in the Old Testament by student J. D. Carling.

5.1.5 Interaction

The level of “interaction” one has with a virtual narrative space determines how much choice one has and how one participates in the story that unfolds as one moves through the space. The ultimate in interaction is being able to shape the environment around oneself as the narrative unfolds. A majority of video games allow for elements in the virtual environment to be manipulated, whether it be ammunition which is collected, opponents that are shot and killed, or doors that can be opened and closed. Some video games now allow for the complete customization of the gaming environment, and include a “level editor” that allows for the user’s own CAD models to be imported into the game.

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"First-person sensory qualities are as important as the sense of agency in creating satisfying human computer experiences. Quite simply, the experience of first-person participation tends to be related to the number, variety, and integration of sensory modalities involved in the representation. The underlying principle here is mimetic; that is, a human-computer experience is more nearly "first-person" when the activity it represents unfolds in the appropriate sensory modalities" [3].

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Using personal service assistant for direct manipulation in smart space

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Abstract

For embodying "Ubiquitous Computing" and "Context-awareness" into smart space design, an interactive model based on "Direct Manipulation" and a smart spatial interface mediated by PDA is demonstrated in this study to emphasize the user's initiative in actuating smart services in space. By the metaphor of WIMP (i.e. Window, Icon, Mouse and Popup-menu) inherited from computer desktop GUI, electronic services and digital information are bundled into physical objects in smart space. For implementation, versatile IT technology and spatial setting are integrated in laboratory, including the RFID, Wi-Fi 802.11 and IR network for context-sensing, device-controlling and service actuation. Through the evaluation in lab demo scenarios, the findings are as follows: (1) the cognitive mapping structure between digital and physical objects derives innovative research issues in user's spatial representation and object labelling for both individuals and groups; (2) the real-time mapping between spatial setting and user status abstracted from sensing network provides rich support for direct manipulation interactions for smart applications; (3) the PSA provides for the habitant extended ability of handheld control-and-display for almost everything.
Keywords: ubiquitous computing, direct manipulation, smart spatial interface, object-aware, personal service assistant, RFID.

1 Introduction

Digital media are incrementally moving beyond digital design tools to interleaving themselves to be integral part of our living environments, especially in an interactive smart space. "Ubiquitous Computing", "Context-aware" and "Attentive Object" [5] provide new perspectives in developing digital

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architecture and smart living. Governmental ICT policies and related projects, entitled as "U-Japan", "U-Korea" and "U-Taiwan" [6], are declaring the next coming ubiquitous era for our everyday living. The smart living proposed in these projects are supported by environments embedded with sensing, communication and computing technology to make possible the integration of the two parallel worlds – digital and physical. However, information which is ubiquitous but overloaded via heterogeneous digital media has to be selectively presented in space at the right situation using the right interface (e.g. tabs, pads or boards). Context-aware services whether mediated by mobile or stationary devices and with active or passive smart applications, have to be provided intuitively to arouse habitants' interaction with the current context. Unconnected devices and multiplex control methods make our digital life filled with cognitive frictions. How to achieve interactive-awareness between habitants and smart space so as to support the subtlety of everyday life becomes our goal and challenge in this study. Based on the approach of "Direct Manipulation", a smart space with tangible interface, digital media, multiple display and wireless sensing network (e.g. RFID, IR and Wi-Fi) is experimented. In order to help the habitants navigate digital information and access chip-controlled spatial services in a common way, collaborative modules of PSA (Personal Service Assistant – a mobile device with abilities of RFID reading and IR controlling) and AIE (Ambient Intelligent Environment) are developed [7]. In this paper, the focus to be discussed is on the PSA applications in this project.

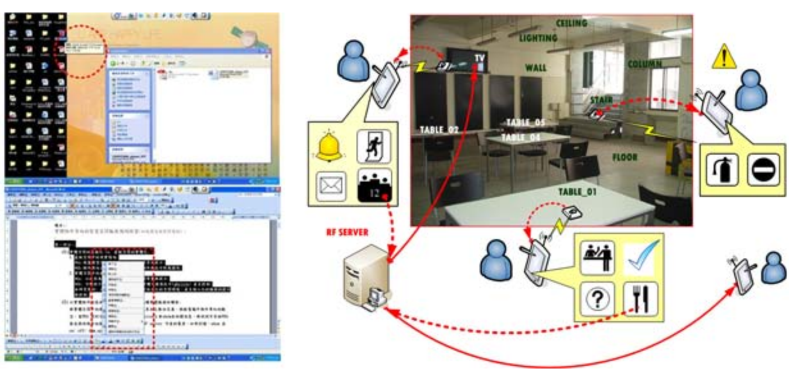

Figure 1: Direct manipulation on window desktop system for file annotation and selection sets menu (left); Direct manipulation proposed for smart spatial interface by PSA (right).

2 Literature review

Related studies apply the concept of semantic location model [8] in CAAD database to the prediction of user's next-coming location for triggering location-based services. This literature depicts the location prediction by pattern learning and data-mining mechanism and simulated on two-dimensional CAAD platform prototype with fixed plan layouts. However, in the real world, the following problems are learned: (1) furniture, fixture or partitions are apt to move and should be able to report to the database on real-time basis; (2) user's next-coming location predicted by statistical result of possibilities is unpredictable while the rates for each directions are close; (3) even located in the same point of a 2D plan, user's intention can be versatile in the three-dimensional space. Based on the above concern, instead of triggering services by location prediction, a diverse approach considered in this study is to support direct manipulation and trigger location-aware services by sensing network in real 3D space. Habitants are able to take the initiative in approaching to their attentive objects (fixed or movable) and intuitively trigger their intended object-dependent services. With the customized digital support from the PSA, the habitants interact with location-aware services on sensing-proximity basis.

3 Previous study: Smart Spatial Interface

People in this "Ubiquitous-era" need an interface system (or mediator) to coordinate the ubiquitous media and computing devices in space. GUI benefited from the metaphor of real-world desktop (e.g. folders, files, etc.) successfully provide hints to the user by mapping real-life experience to the computer desktop. It follows the essence of "Direct Manipulation" and WYSWYG (what you see is what you get); it is composed of window, icon, mouse, pull-down (or popup) menu and is operated by object-oriented command methods and mouse behaviors (ie. button clicking, rolling over, scrolling, etc). With the functions supported by object-oriented methods (e.g. pop-up message-box and service command menu), the GUI desktop displays for each virtual object its corresponding annotation and commands (e.g. icons, selection sets, etc.) which are not available yet for real objects in the physical world. The situated interaction provided under the framework of WIMP inspired this study in bundling electronic services and digital information into physical objects in smart space under the hierarchy of: (1) "Window", the proximity of user's locale anchored by RFID sensing network, (2) "Icons" (or "Phicons"), physical objects attached with RFID tags, (3) "Mouse", a PDA enhanced with RFID-reading and IR device control ability, and (4) "Popup-menus", prompts of object-aware service on a PDA screen (Figure 2).

In the lab works, the Smart Spatial Interface (SSI) proposed in this study is separated into two main developing directions: (1) PSA: user-centred context-aware mobile device and (2) AIE: infrastructure for supporting context-aware smart space by modules of "Event Awareness", "Service Actuation", and "Environmental Status". The PSA interacts with the AIE through user's direct manipulation on spatial physical element and simultaneously call the linkage to database on object basis. Object (i.e. physical element identified with RFID tag) then is selected as the context cue in triggering related spatial services. Most of the physical objects (e.g. photos, books, electronic appliances, door, chair, etc.) are embedded with digital meanings (e.g. content display, action control, etc.). The SSI helps habitant to freely navigate the digital information implicitly carried by components in space and provides situational control menu for currently activated objects. The PSA performs as the mouse in physical space for direct manipulation and the AIE provides supporting environment for service applications actuated by the PSA. The objectives for SSI are: (1) to achieve a universal user interface for smart space; (2) to achieve interactive awareness between user handheld devices (i.e. the PSA) and embedded intelligence in space (i.e. the AIE); (3) to provide real-time object-based annotation for navigation and menu for service control using mobile device; (4) to provide real-time monitoring for people and object status in space. The system model and AIE details are described in related publication [7].

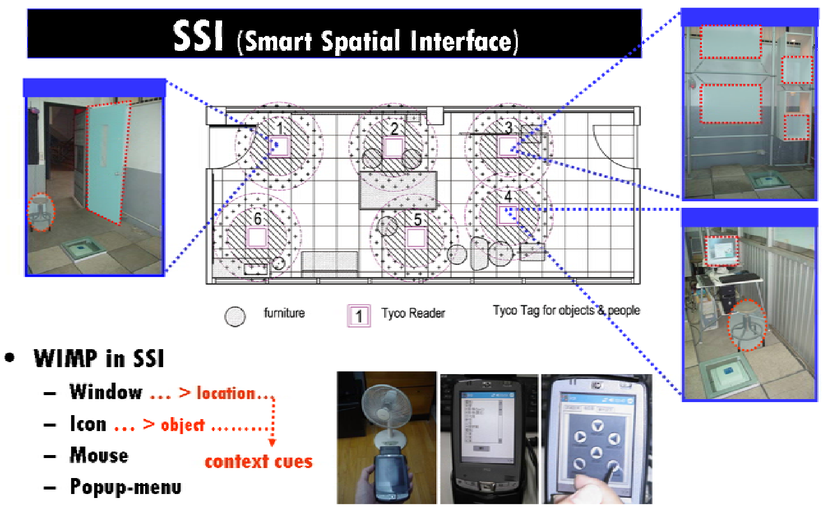

Figure 2: The Window, Icon, Mouse and Popup-menu represented in Smart Spatial Interface.

4 Pointing Device in Smart Space: PSA

A mobile device has become an extension of the person who holds it. These devices are in a perfect position to foster existing interactions and create opportunities for new human-space interactions. In this study, a PSA (Personal Service Assistant) is developed from the market-popular product of WinCE-based PDA with wireless network connecting ability and further enhanced with RFID CF reading ability to interact with any tagged objects in space (e.g. building element, furniture, appliances, personal belongings, etc.). The PSA applies the device-oriented location capability for user-oriented applications to preserve user's initiative. Except for the original functions supported by the PDA (e.g. touch-screen input, calendar, notebook, dictionary, calculator, address book, etc.), at current stage, the main applications appended to the PSA is focus on mediating user's (1) navigation in surrounding environment; (2) personal cross-product cross-species service control interface for any device and media in space. Whenever a person moving in space with the PSA, just like the mouse cursor moving over the icons in computer desktop, user accesses the hidden information of any attentive object and selects on screen from its corresponding service menu which is object-dependent and context-aware. The wireless control signal then is sent from the PSA to RF server or IR server and from server to devices for executing the chosen command. For demonstrating the above idea, sample applications which include scenarios of (1) Message Recall, (2) Media Play, (3) Device Control, and (4) Door Open are implemented (Figure 3).

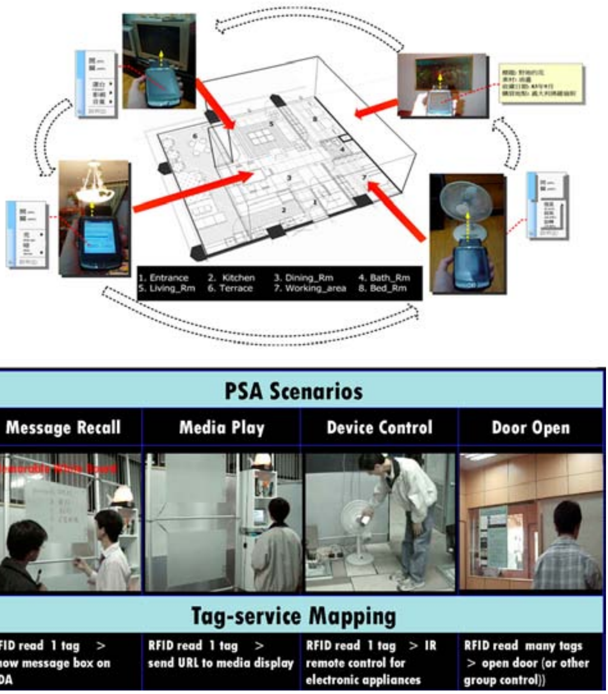

Figure 3: Conceptual diagram for Personal Service Assistant and related application scenarios, the demo videos are available at http://www.nanya.edu.tw/archi/SSI.htm.

5 Object-oriented service providing and data representation

Objects in space can be represented in different taxonomy, granularity requirement and working methods. The roles of objects in this study are: (1) target of direct manipulation, (2) physical-icons (or "Phicons") in space, (3) context cues for interactive awareness, (4) mediator between the PSA and AIE, and (5) portal for service actuation. The related study – "Attentive object" [5] also provides an object-based view in enriching people's natural interaction with everyday objects. Mobile phones become an on-the-move mediator for collecting object's just-in-time information from web search. Based on RFID, Bluetooth, Infra Red technology, user's attention is able to be sensed by object and become an input to interact with people, e.g. Moving Portrait. Comparing with the implicit input style by user's attention used in [5], in this study, a more precise and explicit input style is proposed by using the PSA. And, for output aims, in this study, unlimited to information and media display, a further objective on object-aware control is demonstrated. The object data will adaptively response to user's requirement by reasoning with user's current context which includes the short-term data, (i.e. current location, previously interacted object) and the long-term data, (i.e. personal preference).

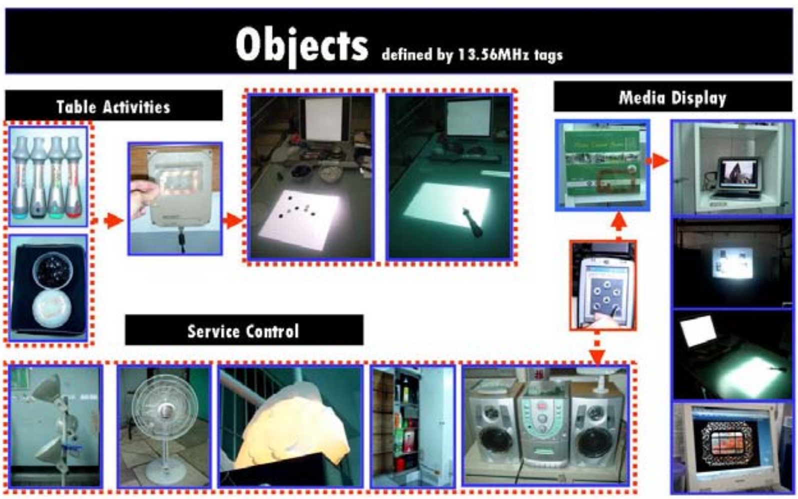

Figure 4: Object-aware service-providing (e.g. control, display and table works) in ambient intelligence environment.

In the digital world of the object-oriented information model, the term "object" represents not only real entities but also virtual ones, e.g. calendar, itinerary, syllabus, etc. In this study, a RFID-tagged-object stands for a pair of object which is physically and virtually connected to each other. For every single object (or group of objects), people may have diverse definitions according to their personal view and user goal. For example, a TV can be a media or videogame player and simultaneously a product for dealer. Based on previous spatial coding summary [7], and following the stages of object-oriented analysis (i.e. finding class-&-object, identifying structures, identifying subjects, defining attributes, defining services), the tagged objects for SSI in this study are defined with class (e.g. TV, Lighting, A/C, etc.) and methods (e.g. Power_on, Voulmn_slider, etc.) (Figure 5). Following the characters of object-oriented data model, object are conceptually with: (1) attributes, operation methods, relations to other objects and identity, (2) class and instance, (3) inheritance from parent class, (4) compound and encapsulation, (5) part reuse, (6) “Noun-Verb” operation (7) object representation models for functional, static and dynamic. [9]

The tables in database are in three categories: (1) fundamental attributes for elements in space (e.g. TV, sofa, table, chair, people, tag and reader, and their background description); (2) definitions for tag-object relationship (one-to-one for normal cases, many-to-one for larger-size objects, one-to-many for object-group commands, which is used for decision- making strategy); (3) event records (stores every event and service actuation for safety and machine-learning use).

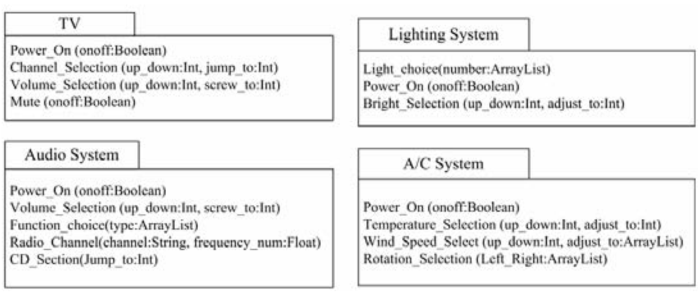

Figure 5: Object-oriented data model represented by class and methods, e.g. TV, Audio, Lighting, and A/C system.

6 Implementation

6.1 System architecture

The system is implemented on the basis of current Wi-Fi networked lab space and further installed with RFID sensing and Infra Red device control networks. The components consisted in the system architecture (Figure 6 – upper) are: (1) PSA: reads the tag id and passes to Smart Service Server via Wi-Fi network; receives signal from Smart Service Server and generates real-time message box or service page on screen; sends back user command to Smart Service Server for control actuation and become a cross-platform smart controller (Figure 6 – lower); (2) RF Device Control Server: receives action commands from Smart Service Server via Wi-Fi network and sends actuation command to RF devices, e.g. lighting and power control, etc. or to IR devices, e.g. projectors, audio player, etc. (3) Database Server: system data centre for records of meaningful events and actions. (4) Smart Service Server: context-manager in coordinating the whole system.

6.2 Technology

The system integration developed in this study is focused on RF- and IR-based control for home appliance, (e.g. projector, lighting, audio etc.) and is coded by

Java and eVB (Embedded Visual Basic) languages. The program module keeps listening to the values transmitted from the external world via RS-232 and sending them to both PC-08 RF Server and RP-08 IR Server (or PS-201) to achieve the purpose of electronic appliances control. The RPC (remote procedure call) supported by Wi-Fi technology enables the eVB programs on the PSA to request its call, via the wireless Wi-Fi network, from the VB, JAVA programs on server and to get response for application. Currently, socket for RPC is applied in this study and the standards of CORBA or Java RMI will be followed to support further interoperability.

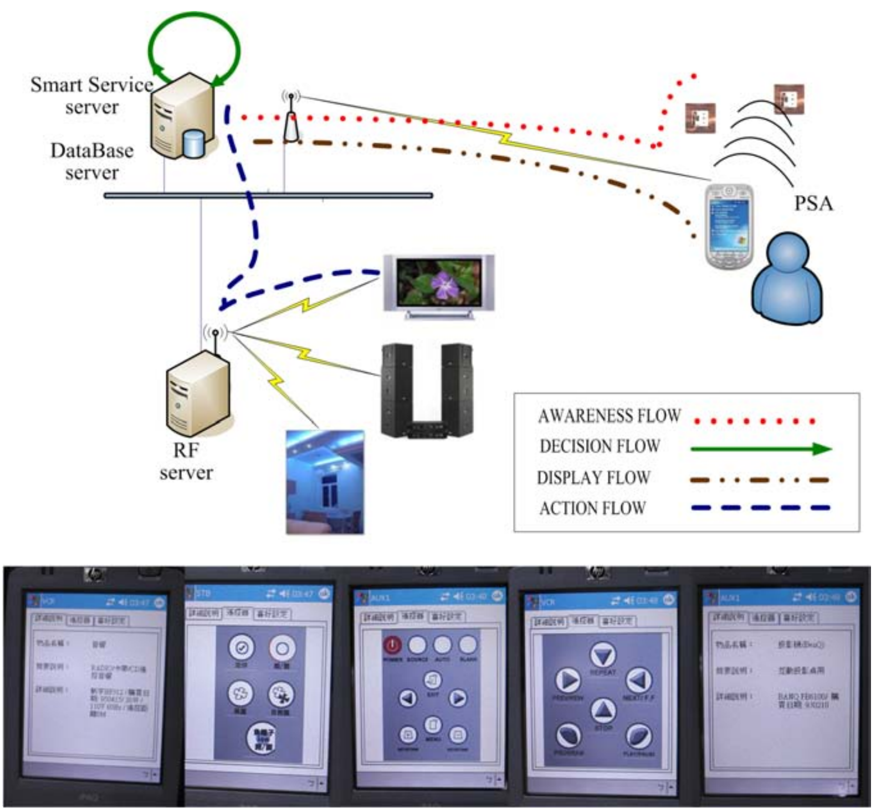

Figure 6: System architecture and information flows (upper) PSA screen pages for object annotation and service controls, e.g. fan, projector, audio player (lower).

In this study, RFID (Radio Frequency Identification) is the main technology used in connecting objects. A RFID system consists of reader, transponder (tag) and back-end API [10]. Species of RFID are identified by (1) Tag type: passive, semi-active or active, according to its power supply. (2) Frequency: 135 KHz, 13.56 MHz, 860~930 MHz (UHF) and 2.45 GHz. In this study, two species of RFID system are applied, i.e. 13.56Hz for the PSA and UHF for smart floor. (Table. 2) The major concern for mobile reader is the limited power supply by the PDA which greatly reduced the sensing proximity. And the major problem caused by the fixed UHF reader is how to adjust the tag into optimal status to keep the sensing proximity.

Table 1: Hardware specification.

Name	Type	Specification	Brand
Smart Home Devices	PC-08 RF Server for PC	Emit. Dist>80M (non-blocked)	TECHCITY
	RP-08 IR Server	Receive Dist>60M (non-blocked) Emit. Dist>7M (straight)	TECHCITY.
	RC-08 3D Remote Controller	Work with Remote controller or RF server	TECHCITY
	WS Lighting Switch PS RF Switch	RF wireless carrier wave for remote control	TECHCITY
PDA	HP iPAQ hx2410	Processor：Intel(R) PXA270 OS: Windows CE 4.21	HP

Table 2: RFID system specification.

Type	Product	Frequency	Brand	Distance
Fixed Reader	agile 2 reader with OmniWave Antenna	UHF	Sensormatic	50cm passive tag
Mobile Reader	V720S-HMF01 For PDA CF type	13.56 MHz	Omron	10cm passive tag

7 Conclusion

In this study, on the objective of developing a ubiquitous smart space, and with the approach of object-awareness, a smart spatial interface (SSI) with mobile device (PSA) is demonstrated to achieve direct manipulation. Findings from this study are: (1) For user applications – the PSA provides for the habitant extended ability of handheld control-and-display for almost everything. The cross-product object-aware interface reduces habitant's cognitive load in acquiring any digital service with personal preferences. Future potentials are providing modes for children, blind people, language translation and group control. (2) For object-management – the object-oriented approach suggested in this study is very user-intuitive in self-updating object information by simply initiating the labelling tags and loading product API via a well-designed server page and attaching/replacing to the new/old objects. (3) For further research issues – conflict compromise mechanisms for multi-device and multi-person contexts and digital-physical mapping structure derived from spatial representation will be the next-step research issues for this study.

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On the integration of digital design and analysis tools

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Abstract

The digital design tools used by architects and engineers today are very useful with respect to their specific fields of aesthetical or technical evaluation. It is not yet possible to fully use the potential of the computer in the design process, as there is no well functioning interplay between the two types of tools. This paper therefore looks at integration of the two types in a prototype for a tool which allows aesthetics evaluation, and at the same time gives the architect instant technical feedback on ideas already in the initial sketching phase.

The aim of the research is to look into integrated digital design and analysis tools in order to find out if it is suited for use by architects and designers or only by specialists and technicians – and if not, then to look at what can be done to make them more available to architects and designers.

The paper contains a case study of three possible approaches for working with digital tectonics by means of acoustics: The architects, the architect-engineer or hybrid practitioner and finally a prototype for a possible digital tectonic tool. For the third approach in the case study, a prototype digital tectonic tool is tested on the design proposal for the auditorium in the planned Utzon Centre in Aalborg, Denmark.
Keywords: tectonics, digital tectonics, design tools, Utzon, reverberation time, generative components.

1 Introduction

Architects and engineers both employ iterative multi-stage design procedures, starting with initial conceptual design and progressing to more detailed final design. The conceptual design for an architect can be very abstract, with content

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that might be more poetic than geometric. On the other hand the conceptual design for a structural engineer tends to be more tangible in nature, i.e. the choice between an arch and a suspension structure, between concrete and steel [1].

Today different types of digital design and analysis tools exist which can support architects as well as engineers during the design process. An integration of these design and tools would allow the engineer to take full advantage of the opportunities provided by the architecture, at different levels of refinement, by directly deriving structural schemes from the 3D model. It also allows the architect to receive more opportune and informed structural feedback, and to detect structural problems earlier in the process. At the core of this approach lies a design representation that describes relevant information to both disciplines in a uniform framework and reflects the strong interdependency between the architecture and the structure.

An area in architecture where aesthetics and structure are interconnected is within tectonics. With the word "Tecton" meaning a carpenter or builder, and the "Archi-Tecton" meaning a master-builder [2], then the possibilities for a contemporary translation of tectonics could be very wide.

The definition used in this article is the one, where the goal in tectonics is to use materials in accordance with their physical properties, and the design of an honest displayed construction [3].

Roughly building design can be viewed as a process where the architect formulates the guides within which then the engineer designs the construction. This causes a linear work flow in the process, and once engineers have started projecting the building it will be very costly to go back into modifying the overall building shape, if something would show to be disadvantageous in the design – e.g. an unwanted acoustical environment. These things should not happen in tectonic design where technical considerations are integrated in the initial sketches.

Tectonic design being construction design on one hand contains a lot of thoughts on statical, acoustical and other functional parameters. It also has to fulfil the aesthetical demands from the architect. Therefore it is advantageous for the process that the architect has knowledge of both technical and aesthetic aspects and uses them already in the early design phase.

1.1 Digital tectonic tools

In the world of modern architecture computers are – apart from managing and controlling the building process – mainly used for two purposes. That is to make virtual representations of spaces or for photorealistic renderings [4]. The first is mainly to investigate and form and to describe complex shapes that would have been difficult, if not impossible to describe in 2D planar drawings. Renderings are also mostly used for investigating or presenting a design visually.

One way of moving tectonic design forward in modern architecture is to use the potential given by various computer programmes, which are available today. Various computer programmes are used in the design of buildings, but as it is today there is often a separation between the tools used for generating the shape and the tools used for e.g. verifying the statics or acoustics etc. of a building. The problem is that this part of the design process is carried out by other people than the architect, which maintains a status quo for the integration of computer tools in the process, as the understanding is with someone else than the architect.

The range of tools is wide, where on the one hand the architect can turn towards programmes primarily made for visualising and illustration of conceptual ideas, or on the other hand to the other extreme of numeric calculation tools for designing optimal solutions, originating from civil engineering. With the development of computer tools for e.g. structural optimization it is possible for an architect with statical know-how, to use these programmes as the design driver [5].

To be able to use the tools, which are mainly developed within the field of civil engineering, it is necessary to have a fundamental understanding of the technical areas in play. The programmes existing today are mainly designed for engineers and technicians and are used for verification of the building some time after the initial sketches are developed by the architect. These computer programmes are available for simulating e.g. the physical properties of a construction or acoustical environment, which would be of great use for architects to be able to influence in order to develop their designs.

A new generation of computer tools for architectural design should provide the possibility for the architect to work with both the aesthetic as well as the technical aspects of architecture.

The aim of this research is to look into integrated digital design and analysis tools in order to find out if it is suited for use by architects and designers or only by specialists and technicians – and if not, then to look at what can be done to make them more available to architects and designers.

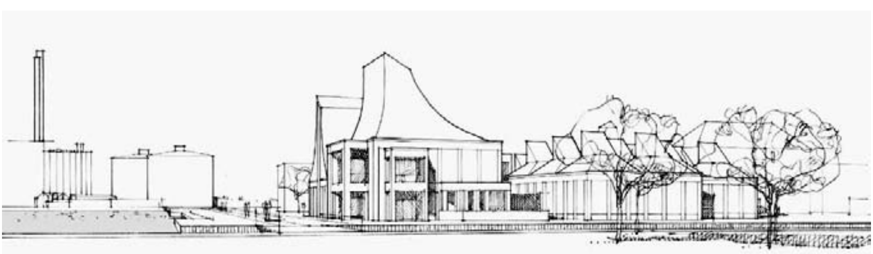

Figure 1: Sketch of the Utzon Centre Aalborg.

For the case study of the various design approaches the roof structure over the 240m^2 auditorium in the Utzon Centre in Aalborg, Denmark, is used as basis. More precisely the case study looks at different approaches for shaping the roof acoustically.

Three different approaches will be presented in the following section. The first is the typical architects approach. The second is the approach of the architect-engineer or hybrid-practitioner, and after a short evaluation of the two approaches a third approach, which describes a prototype for a digital tectonic tool.

2 Possible design approaches

If an architect would design the roof structure all over again, what are then his possibilities? Roughly there are, as we see it, three different approaches to the design of an acoustical roof shape:

2.1 The architects approach

The first one, which is the geometric acoustical way to do it for an architect with some acoustic knowledge, and also a technique which Jørn Utzon is known to use, is to do a sketch of the desired curvature, and then, by drawing lines, projecting sound, onto the surface and then under the assumption that the angle of incidence equals the angle of reflection, to design a assumed diffuse sound field.

This approach is quite useful for architects and does not require any tools apart from paper and pen. A small amount of knowledge about acoustical design is required, but only what an architect would be assumed to know. The method is simple and does not require help from an acoustics expert. Therefore it is very useful in the early sketching phase, as new sketches for shaping the roof, can easily be investigated at a low consumption of man-hours.

In any design process the testing of a large number of sketches may be required to get the right aesthetic solution, and the approach above is suited for this design process.

What probably happens once the architect feels that he has reached a desirable design is that the drawings are then handed over to an engineer, who calculates reverberation times for the room or makes an auralization – a simulation of the acoustical environment, to verify that the room fulfils the desired requirements.

The final adjustments of the design might in this case end up being made by an engineer, who might not make the same aesthetical considerations as the architect, fig. 2 (a). One problem in relation to this step in the process is that once the engineer is involved, then costs go up because of the man-hours spent. This problem is what sometimes causes struggle between the architects and engineers, when the architect does not approve of the modifications, and wants to do a new iteration on the design.

2.2 The hybrid practitioner approach

The second approach is one which falls within the definition "Digital Tectonics" as it is described by Neil Leach et al in the book with that exact same title, where an architect-engineer or hybrid practitioner works simultaneously with both aesthetic and technical, in this case acoustic, design requirements [6].

With "tectonics" understood as structural or in this case acoustical parameters in play as design drivers rather than detaching them from the architectural design process. "Digital" as it is dependent on the digital tools available on the market. These digital tools are programmes like CATT [7] and ODEON [8], which can calculate reverberation times and do auralization [9].

This kind of tools requires a substantial acoustical knowledge, in order to be able to use them in the initial sketching phase.

When that knowledge is present the architect will be able to take the results – the reverberation times and the auralization, from the programmes into consideration before the drawings are sent to the engineers for verification, if that is even necessary. The results from the architect's calculations are likely to be as accurate as the ones that an engineer would come up with, as the tools he would be using are the same.

This accuracy is on the other hand also the problem of this working approach. Every time the architect wants to do an iteration on the design, then he will have to draw a new sketch, likely by hand, build or modify a 3D CAD model of the room, import it into the programme and prepare if for calculation inside the acoustical simulation programme, before he can get the feedback that he needs to evaluate the acoustical properties of the design [10].

As the input for these programmes has to be very accurate in order to give the correct result, then this work process of doing an iteration is a slow way of developing a design. Therefore it might not be so suited for the initial sketching process [11].

The problem is that the interaction with the geometry of the design is done in CAD, and the acoustical feed back which causes the architect to alter the design comes from a different programme, fig. 2 (b). Going from one programme to the other is very time consuming, and it is not a good way of testing a couple of ideas in a hurry.

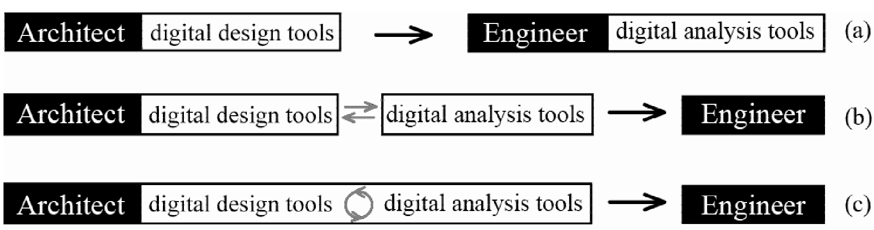

Figure 2: The three approaches – (a) the architects, (b) the hybrid practitioner and (c) the approach provided by the prototype, showing the initial sketching phase on the left side of the black arrow and the detailing phase on the right side.

2.3 Problem identification

The two previously described cases reveals that both the architect and hybrid practitioner cannot use the potential of the computer in the early design process.

For the architect to be able to use the computer programmes, they will have to contain an embedded knowledge that the architect can benefit from, perhaps without knowing all the theory behind the various calculations in the computer programme.

For the hybrid practitioner who knows about the, in this case, acoustic theory, the interesting next step would be to provide a tool, in which he could change an amount of desired design variables, without having to start from scratch with the CAD model every time that the design changes, so that the flow in the sketching process is not interrupted, as it is important to be able to iterate quickly in the early sketching phase [12].

The ideal tool for the sketching process would therefore be one, in which the geometry of the model could easily be manipulated and provide the acoustical feedback real time, fig. 2 (c).

3 The Utzon Centre in Aalborg

The Utzon Centre on the harbour front of Aalborg is designed by Jørn Utzon and his two sons, Kim and Jan Utzon, and it is going to function as a cultural institution, where architects, student and others can meet or hold conferences.

The centre also contains a library and archives with most of Jørn Utzons sketches from his office.

Jørn Utzon, who is best known for the Sydney Opera House, is as an architect very concerned with creating quality for the users, in the buildings he designs. This humanistic approach is reflected in design of the centre and in the modest scale of it.

The desire to make a good environment for the users is also reflected in the way Utzon works with natural lighting and acoustics in his buildings. These matters are treated with great attention and with Utzon, as many other architects in the modern movement, underline the relation where form is derived from its function [13].

"It's the construction I am interested in… I want to expose it. That is something that I have learnt from nature."

Jørn Utzon

The Utzon Centre is an example of Jørn Utzon's concepts for additive architecture, which he developed as far back as in the 1960s, where he made a proposal for the Export College in Herning, Denmark, in a very similar way.

The design, with its many cubes and varying roof shapes is very much inspired by Utzon's studies of Arabian bazaars; the various roof shapes derive from the demands from the functions below them, regarding light and volume [14].

Three distinct roof structures are seen on the building. One is over the library, another over the workshops and the last on over the auditorium. This article focuses on the design of the roof structures over the auditorium.

"… and there is an acoustically shaped roof, which rises high above the seat, and then you have a number of large niches that you look out through, which frame a picture for each seat, of the fjord…"

Jørn Utzon

3.1 The new digital tectonic approach

The third design process approach in the case study is an initial proposal for a prototype for a digital tectonic tool developed in the computer programme 'Generative Components' [15]. It is a good basis for a prototype for such a digital design tool, as it can provide real time feedback to the architect, when the design is modified.

The aim with the prototype is to investigate the possibility to use 'Generative Components' as digital tectonics tool which could be useful in an early design phase by allowing the architect to manipulate the shape of the roof structure – In this case the auditorium in the Utzon Centre – and at the same time give the architect real time feedback on the reverberation time and the visual looks of the room.

The prototype is able calculate the reverberation time using Sabine's formula:

$$T_{Sabine} = 55{,}3 \cdot \frac{V}{c \cdot A} \tag{1}$$

where T_{Sabine} is the reverberation time [s], V is the Volume of the room [m^2], c is the sonic speed of sound at 21°C [m/s] and A is the area of the surface multiplied by the absorption coefficient of the material of the surface [m^2].

For an auditorium to be a good acoustic environment for speech, then the reverberation time should to be around 1.0 to 1.3 in the 500Hz band.

'Generative Components' is a parametric design tool which has uses in many areas other than acoustic design, but the programme was chosen as it facilitated a good possibility for interaction with external computer programmes compared with conventional design tools like Rhino.

The design of the geometry in the prototype is very determining for which parameters the architect wants to be able to manipulate. These variables must be chosen before building the geometry. Otherwise too radical changes to the geometry may corrupt the 'TransactionFile' which keeps track of relation between different parts of the geometry. It would therefore be likely that a complete rebuild of the geometry could be necessary if new design variables are necessary. Dependent on the complexity this might be a time consuming task which suggests that initial sketching with pen and paper would be appropriate before 'tuning' the design in the 'Generative Components' model.

This prototype allows the user to change the curvature of the roof with two variables, which are setup in 'Generative Components' as sliders that control the midpoint of the *B*-spline curves which delimit the roof.

The prototype provides the desired feedback for the architect and works without any problems. When changes are made in geometry in the CAD programme, then the reverberation time is updated real time in the spread sheet, where the calculations are made.

The combination of visual feedback of the shape in combination with acoustical feedback in the way of reverberation time is a good combination for tuning a design before it is handed over to the engineers for final projecting.

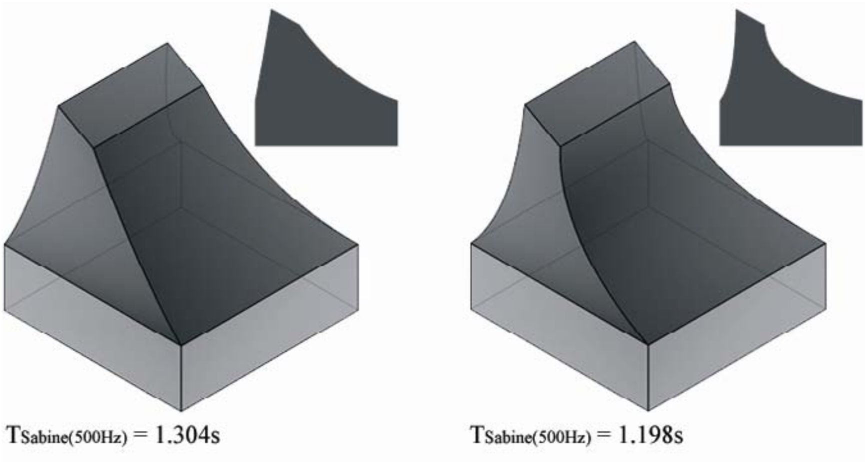

Figure 3: Examples of geometry and reverberation time from the prototype.

The prototype is suited for simple acoustical considerations, but far from as sophisticated as acoustical simulation programmes. Also, because of the specific focus on the Utzon Centre roof structure, the geometry is very specific for this one project. To do other projects the prototype will have to be rebuilt. As this is a time consuming and not suited for initial sketching, with the exception of cubical rooms for which a general prototype could quite easily be build. The only design variables needed would be the length, width and height of the room and the damping coefficient of the materials of the various surfaces.

The choice of materials is made with different approaches, depending on whether you are an acoustics engineer or you are an architect. Where an acoustics engineer would choose materials with the aim to make a good acoustic environment he might not consider the same qualities in materials as an architect, who would look for the right colour, tactility, texture, reflectivity, transparency etc.

On the other hand an architect would perhaps not be looking for materials with the right acoustical properties as a primary objective. If these properties were embedded in the CAD-program, then the architect would have what could be called 'extended' knowledge, which would be available when designing a room.

With the prototype an architect would be able to test materials and know the reverberation time of the room, without having to consult the engineer for this.

4 Conclusion

In this paper three possible approaches to tectonic architectural design are discussed. With the computer technology available an integration of design and analysis tools could give the architect a possibility to get instant feedback on ideas already in the initial sketching phase.

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The three approaches show, that both the architect and hybrid practitioner cannot yet use the full potential of the computer in the design process. That is because the existing computer programmes are developed to sustain the work of either the architect or the engineer. The interaction between the two types is so far not working seamlessly.

A programme which could sustain the work of the architect without having to involve a technician in the early design phase seems to be desirable. The program should contain an embedded knowledge which the architect can benefit from, regardless if he knows all the theory behind the programme.

A hybrid practitioner, who already knows the theory, stands to gain speed by the tools, as the design iterations can be done instantly and provide real time feedback.

The new digital approach prototype is fitted only for the given geometry, and more general tools are still to be developed. Before they do it is up to the architect or any other user of the programmes to build them. The role of the architect is then to describe beforehand, the design parameters that he or she wants to be able to manipulate. In that way, he or she stands to gain, for the particular case, a very usable tectonic tool. This kind of 'extended' knowledge could also sustain the cognition of various physical behaviours, if the prototype was used for educational purposes.

Concerning the results from the prototype it should be stated, that the reverberation time is only a function of volume, surfaces and damping coefficients. Other parameters like distribution of sound are not regarded in this case study. Also, if instead of doing the Utzon Centre auditorium had done simple a square room, with variable height, width, length and surface materials, one would have a tool that could find a more general use.

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Evaluation of the urban regulations by three-dimensional modelling: the district of Providencia in Santiago, Chile

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Abstract

This paper presents a methodological approach for the evaluation of the urban regulation and its application to a real case in the district of Providencia in Santiago, Chile.

As opposed to the traditional textual-discursive and two-dimensional elaboration of the urban regulation, the digital instruments allow an immediate verification of the generated volumes, as well as the alternatives of variation and contradictions that it contains. The three-dimensional modelling is used as an instrument capable of showing efficiently the immediate verification of the instruments proposed within the urban changes and dynamics. It also offers the possibility of generating the norm itself from a sequence of procedures that gathers the dynamics of transformation and models them like a series of possible situations. Considering that all urban norms have a pretension and formal result, the methodological approach proposed starts from the shape and the dynamics for the creation of the norm.

This paper will show particularly the three-dimensional model of the norms on the existing property layout, and the volumes that it proposes in relation to the property division and its variation (property fusion, highly frequent condition in the cities of the developing countries), and evaluates its effects according to the site coverage, plot area ratio, and setback. The three-dimensional modelling of the volumes generated by the regulation was made using the software AutoCad, 3dStudio, FormZ, Excel, and its linkings.
Keywords: urban regulation, three-dimensional modelling, urban dynamics, urban transformation, visual analysis, norm, normative.

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1 Introduction

The urban norms tend to regulate the urban form, through the establishment of an ideal form, by means of a series of clear, precise and stable parameters. Nevertheless, the development of the urban form is being determined by patterns apparently disorganized and impelled by private managements with diverse rules. The form conception habitually contained within the norms supposes a stabilized urban dynamic.

In countries with accelerated economical growth, the maximum volume allowed by the legal norm is rapidly transferred to reality, reason why, the three-dimensional parameters of the laws suggest a form of city.

As opposed to the traditional textual-discursive and two-dimensional elaboration of the urban regulation, the digital instruments for the formal generation, allows an immediate verification of the generated volumes, as well as the alternatives of variation, contradictions and possibilities that the same regulation contains.

The three-dimensional modelling is used as an instrument capable of showing the conditions of the regulations against the changes and urban dynamics, and permits rapidly and efficiently the immediate verification of the instruments proposed within those dynamics; for example, the formal implications of the variations of the plot area ratios affected by the property fusion. But it also offers the possibility of generating the norm itself from a sequence of possible procedures that gathers the dynamics of transformation and models them like a series of possible situations. Considering that all urban norms have an implied purpose and formal result, the methodological approach proposed starts from the shape and the dynamics for the creation of the norm.

This paper presents a methodological approach for the evaluation of the urban regulation and its application to a real case in the district of Providencia in Santiago, Chile. The urban form of Providencia comes from the model of garden city and the principal normative instruments are: the “setback” (*rasante*), the “front yard” (*antejardín*) and the “plot area ratio” (*constructibilidad*) [1]. For some time now, it has been arranged to promote the fusion of properties with an extra 30% of the plot area ratio, maintaining the restriction of the “site coverage” (*ocupación de suelo*) to 40% [2].

In this paper, the three-dimensional modelling of the existing regulations applied to an existing block is exposed.

The regulation set of the district of Providencia was analyzed using mathematical models to discover the method of formulation and implications of the values that are managed within the district.

2 Three-dimensional modelling of Providencia’s regulation

The visual analysis of the ordinance, consists in three-dimensionalized the normative variables that define the built-up form; especially through its limiting to the maximum building volume allowed in every property.

A block that was in a zone of possible imminent transformation was chosen. On this block, successive hypotheses were applied taking into account the incentive for the fusion of properties, which allows an increase of the plot area ratio and therefore greater success in the economic aspects of the real estate operation that it assumes. The supposed situation of unions between neighbouring properties mainly inclined to be fused was considered (fig. 1).

In order to spatially visualize the norm proposal, six successive modelling and analyses operations were carried out using Autocad, FormZ, 3d Studio and Excel.

2.1 Operation_01

Polygons were defined for each possible property fusion according to the demarcations between the grouped properties and the axes of the roadways that they face. From them, following the setback a pyramid is raised with an inclination of 70º, as the norm establishes it for Santiago (fig. 2).

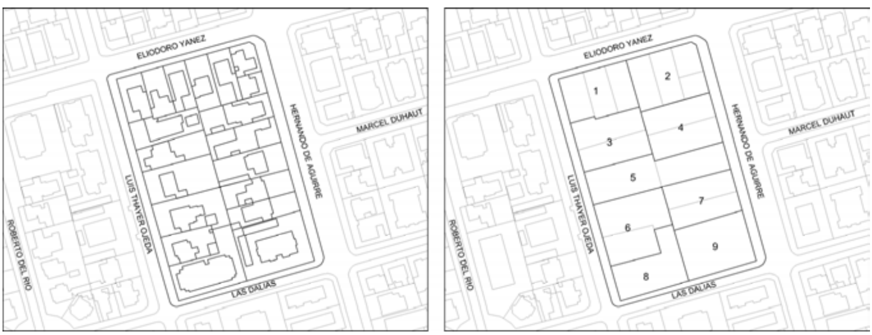

Figure 1: Chosen block (left) and possible property fusion (right).

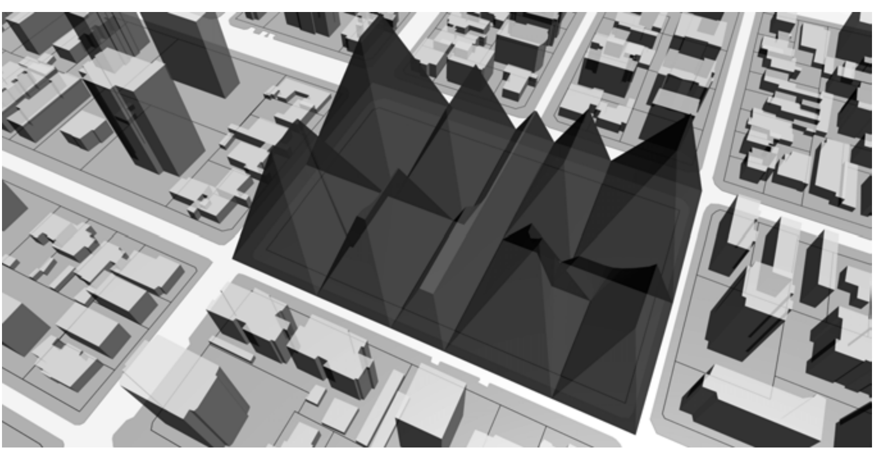

Figure 2: Volumes defined by the setback (*Rasante*) for each property fusion.

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The setback (*rasante*) is an imaginary straight line that, in a certain angle, defines the theoretic surrounding in which a construction project can be developed. This angle in Santiago is 70º. The *Rasante* will rise in all the points that form the border with other property and in the midpoint between official lines of the public space that faces the property.

2.2 Operation_02

The *Antejardín* (front yard) is the area free of construction between the official line and the line of building. To translate this to volumetric representable conditions, three volumes were formed with the options of the "extrude" command in AutoCad, and then joined one over the other as shown in figure 3.

a) The first volume that rises from the polyline limited by the boundaries with other properties and the retreated line in 5 m (16,40 ft) from the sides that face a street. This polyline is extruded in 90º, 16 m (53,49 ft) high.

b) The second volume: – sort of a truncated pyramid – extruded 14 m (45,93 ft), with an inclination of 73,3º, or an "angle of taper for extrusion" of 16,7º (90º - 73,3º), resulted from the 30 cm (11,81 ft) retreat per every meter gained in height.

c) The third volume has a pyramidal form. It is raised from the polyline limited by the "plateau" of the previous volume, extruded with an inclination of 59º until his faces join, resultant of the 60 cm (23,62 in) retreat per every meter gained in height.

2.3 Operation_03

A final volume is constituted using AutoCad's "intersection" tool. This volume is defined like the intersection of the space limits of the *Rasante* and the *Antejardín* (fig. 4). Thus, the conditions that govern each project individually are graphically revealed on the scale of the block.

2.4 Operation_04

On the obtained volumes, the tool "contours" of the program FormZ was used. This tool makes consecutive sections of a volume at a defined distance. In this case, horizontal sections every 2,5 m (8,20 ft), simulating the height of a housing building (fig. 5).

The result is a series of possible outlines or silhouettes of repeatable floors with the intention of creating volumes that avoid the inclined planes of the resulting project, but staying within the volumetric margins limited by the norms.

2.5 Operation_05

With the data of the ratios and the area of each of the property fusions, a table was generated in the program Excel that shows the maximum building area allowed in each group, considering the increase of 30% of the plot area ratio by property fusion, resulting a plot area ratio of 2,08 (table 1).

Figure 3: Volumes defined by the front yard regulation (*Antejardín*) for each property fusion.

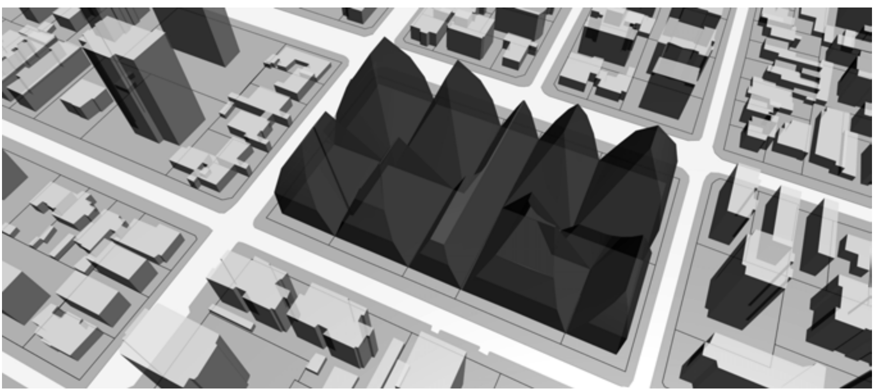

Figure 4: Volumes defined by the intersection of the space limits of the *Rasante* and the *Antejardín.*

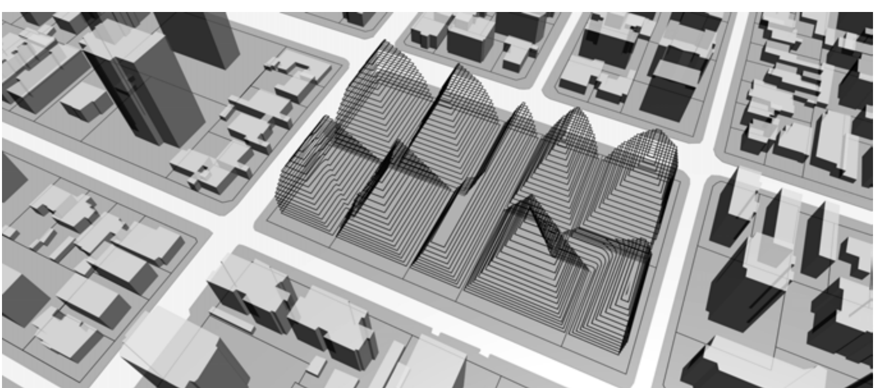

Figure 5: Possible silhouettes of the final volumes made with the FormZ command “contours” every 2,5 m (8,20 ft).

The resulting area was divided into “floors” (numbers in **bold**), and were compared with the areas of the “contours” (numbers in *italic*), looking for the pair with smaller difference (marked in grey).

It is very improbable that both numbers match, so a “margin of inaccuracy” of until a 25% of the area of “contour” over the corresponding “floor” was used.

2.6 Operation_06

The numbers marked in grey in table 1 would be the area of the “contour” to be extruded to shape the volume that represents a building in the model.

Figure 6 is a graphic response that visualizes the spatial consequence that is being stimulated by increasing the plot area ratio by property fusion.

Table 1: Comparative table of the areas of the contours (numbers in *italic*) and the distribution of the maximum building area in floors (numbers in **bold**).

Property fusion	1	2	3	4	5	6	7	8	9
Property fusion area (m^2)	1645,9	1881,9	1701,7	1771,3	2156,9	1986,6	1528,9	1458,9	1828,1
Property fusion area x 2,08 (m^2)	3423,5	3914,4	3539,5	3684,3	4486,4	4132,1	3180,1	3034,5	3802,4
8 floors	**427,9**	**489,3**	**442,4**	**460,5**	**560,8**	**516,5**	**397,5**	**379,3**	**475,3**
	709,6	*884,6*	*705,2*	*762,7*	*592,5*	*871,3*	*586,2*	*414,5*	*843,7*
9 floors	**380,4**	**434,9**	**393,3**	**409,4**	**498,5**	**459,1**	**353,3**	**337,2**	**422,5**
	619,5	*786,5*	*608,8*	*664,7*	*423,7*	*761,8*	*496,4*	*335,3*	*747,8*
10 floors	**342,3**	**391,4**	**354,0**	**368,4**	**448,6**	**413,2**	**318,0**	**303,5**	**380,2**
	535,0	*693,9*	*518,5*	*572,8*	*260,5*	*658,7*	*412,6*	*263,1*	*657,3*
11 floors	**311,2**	**355,9**	**321,8**	**334,9**	**407,9**	**375,6**	**289,1**	**275,9**	**345,7**
	456,0	*606,8*	*434,3*	*486,9*		*562,0*	*334,9*	*197,1*	*572,4*
12 floors	**285,3**	**326,2**	**295,0**	**307,0**	**373,9**	**344,3**	**265,0**	**252,9**	**316,9**
	382,5	*525,2*	*356,2*	*407,0*		*471,7*	*263,2*	*136,8*	*493,0*
13 floors	**263,3**	**301,1**	**272,3**	**283,4**	**345,1**	**317,9**	**244,6**	**233,4**	**292,5**
	286,6	*416,5*	*275,3*	*324,2*		*372,1*	*192,5*	*59,4*	*387,5*
14 floors	**244,5**	**279,6**	**252,8**	**263,2**	**320,5**	**295,2**	**227,2**	**216,8**	**271,6**
	202,5	*319,3*	*203,4*	*250,2*		*281,6*	*130,6*		*293,6*

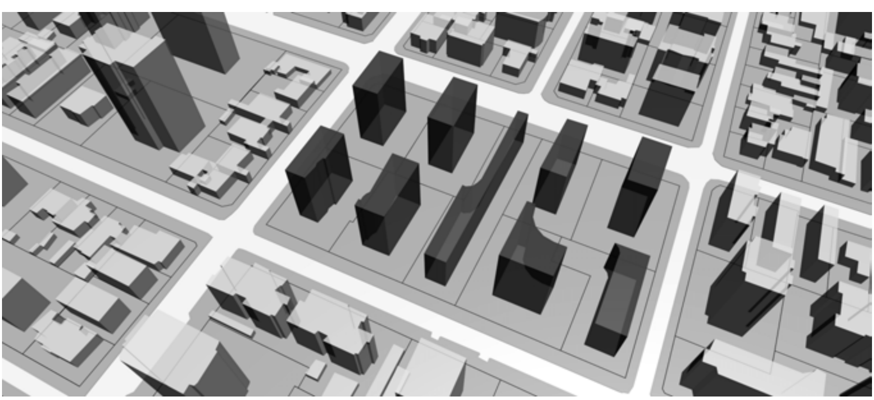

Figure 6: Graphic response of the regulation of Providencia.

3 Analysis of the combination of normative variables

Behind every norm there is a city model. The digital technology allows, in an efficient way, to recognize this model, but also allows, in the way of evaluating its possible effects that are not clear enough in the application of a traditional set of instruments that has had only partial, graphic or written formulations.

With the interest of analyzing the combination of three variables that delimit the volumes, plot area ratio, site coverage and setback (*rasante*), different software were used – Matlab, Excel and AutoCad. For this study they were considered the same numbers proposed in the previous exercise.

3.1 Plot area ratio (*constructibilidad*) and site coverage (*ocupación de suelo*)

The *constructibilidad* (plot area ratio) is the number that multiplied by the total surface of the property, equals the maximum square meters allowed to build.

The *ocupación de suelo* (site coverage) is the percentage of the surface of the property that is allowed to be built on the ground level.

Figure 7 shows the volumes that the combinations of these variables create.

For example, a plot area ratio of 2,08 and a site coverage of 40%, being coefficients of the same number – the surface of the property – the number of floors to construct is obtained dividing one in the other. That is, 2,08 ÷ 0,4 = 5,2 floors (without considering 20% of public use).

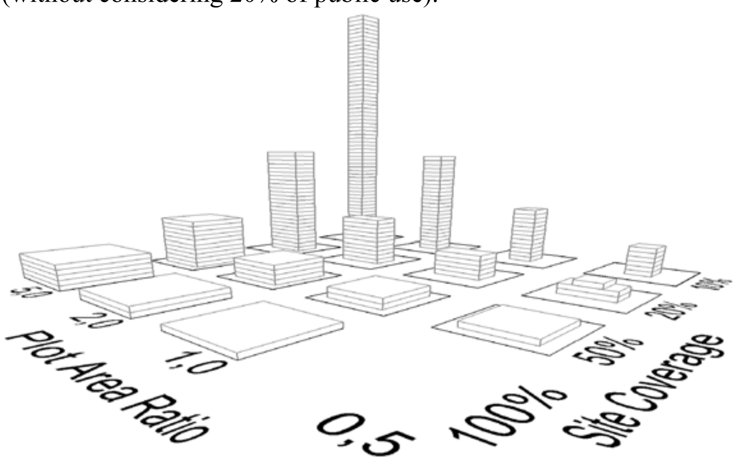

Figure 7: Diagram of the combination of the plot area ratio and the site coverage.

3.2 Setback (*rasante*) and plot area ratio (*constructibilidad*), with respect to a fixed site coverage (*ocupación de suelo*)

In order to define the maximum building volume that results from the combination of the *rasante* and the *constructibilidad*, it was defined the variable "y" as the distance to the border (fig. 8), and the constants "a" and "b" as the width and length of the property, respectively and they vary between 9 and 60 m to cover the totality of existing sites in the district.

Thus, and considering an *ocupación de suelo* of 40%, the following equation appeared:

$$(a-2y)\,(b-y) = 0.4ab \tag{1}$$

With the results of the equation (1) a matrix – in Excel – was generated that shows the uniform distancing towards each edge, in meters, of an area of a 40% of the property. From this first matrix, was generated a second matrix, that shows at what height this area intersect with the *rasante* of 70º.

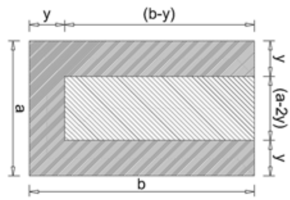

Figure 8: Explanatory diagram of the proportions in equation (1).

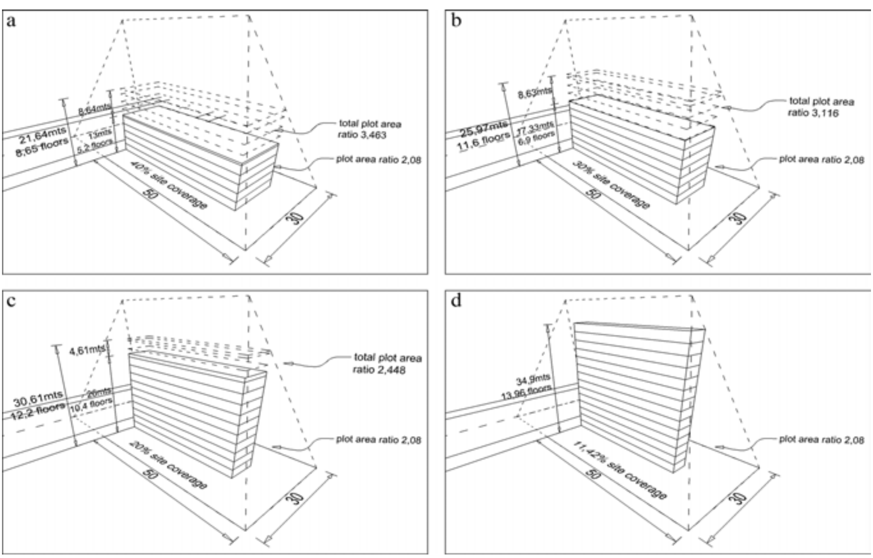

Figure 9: Diagram of the volumes allowed by a site coverage of (a) 40%, (b) 30%, (c) 20% and (d) 11,42% in an example property of 30x50 m.

A third matrix was generated considering floors of 2,5 m high. This shows the *constructibilidad* of each one of these volumes, and reveals that with a site coverage of 40%, there are very few properties that have a *constructibilidad* of 2,08, and besides, given their proportions, either they do not exist in the district or they can't be formed by fusion of properties. It also shows that the *constructibilidad* that would fulfil this conditions, is much more than 2,08, but in no case it would exceeded 9 floors of height (fig. 9a). The same matrices were elaborated for site coverages of 30% and 20%, obtaining results that show the current alternatives of construction in the district, higher buildings and less site coverage (figs. 9b, 9c and 9d).

3.3 *Ocupación de suelo* and *rasante*, with respect to a fixed *constructibilidad*

This problem was solved and illustrated using the software Matlab as shown.

"a" and "b" are the values in meters of the width and length of the property respectively, and "p" is the site coverage measured in percentage (fig. 10).

```
syms a b p

P = solve((a-2*(1/4*a+1/2*b-1/20*(25*a^2-
100*a*b+100*b^2+2*a*b*p)^(1/2)))*(b-(1/4*a+1/2*b-1/20*(25*a^2-100*a*b+100*b^2+2*a*b*p)^(1/2)
))*((1/4*a+1/2*b-1/20*(25*a^2-100*a*b+100*b^2+2*a*b*p)^(1/2))*tan(7*pi/18)/2.5)/(a*b)-2.08,p);

Q = solve((a-2*(1/4*a+1/2*b-1/20*(25*a^2-
100*a*b+100*b^2+2*a*b*p)^(1/2)))*(b-(1/4*a+1/2*b-1/20*(25*a^2-100*a*b+100*b^2+2*a*b*p)^(1/2)
))*((1/4*a+1/2*b-1/20*(25*a^2-100*a*b+100*b^2+2*a*b*p)^(1/2))*tan(7*pi/18)/2.5)/(a*b)-1.6,p);

p1=zeros(60);
p2=zeros(60);
p3=zeros(60);

q1=zeros(60);
q2=zeros(60);
q3=zeros(60);

for a=1:60
  for b=1:60

    p1(b,a) = eval(real(P(1)));
    p2(b,a) = eval(real(P(2)));
    p3(b,a) = eval(real(P(3)));

    q1(b,a) = eval(real(Q(1)));
    q2(b,a) = eval(real(Q(2)));
    q3(b,a) = eval(real(Q(3)));

  end
end
```

Figure 10: Input of the equations in Matlab language for it to solve.

Each equation ("P" and "Q") returns three matrices (p1, p2, p3, and q1, q2, q3) like results for each property (a,b). These matrices show the percentage of coverage, that extruded until the height which they touch the *rasante* and divided

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in floors of 2,5 m high, are equivalent in constructibilidad to 2,08 and 1,6, even if its not an exact number of floors. This is illustrated in figure 11.

This shows that does not exist only one coverage that responds to the demanded *constructibilidad*, but three possible coverages to reach a *constructibilidad* of 2,08 and 1,6 in every property, but that in the properties that might result from a property fusion, 40% of coverage is not a restrictive value.

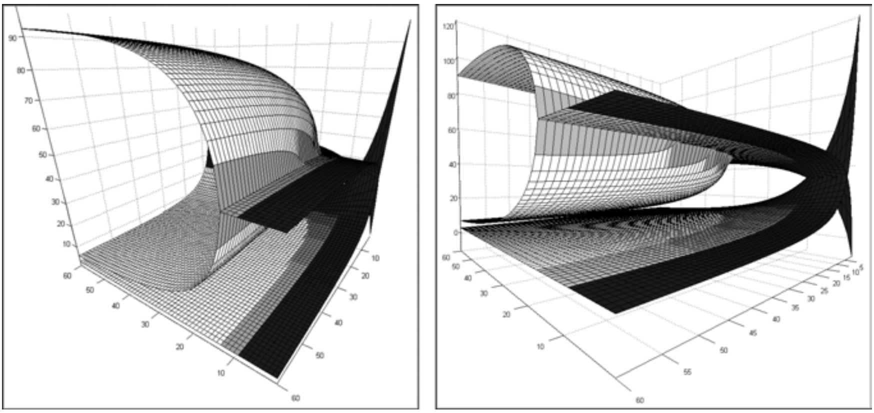

Figure 11: Three-dimensional graphics generated in Matlab, which shows three possible site coverages (in percentage) that a *constructibilidad* of 1,6 (left) and 2,08 (right) would allow for every property. The grey zone represents the existing properties in the district, and the white zone the possible sites formed by fusion of properties. The properties represented by the black zone do not exist, but they were included in the graph for his continuity.

4 Final remark

The modelling of the regulation allows verifying that the possibilities are grater than the initially foreseen by the norms. For example for the point "3.2 Distancing & plot area ratio, respect a fixed site coverage", it verifies that when 40% of site coverage is restrictive, the *constructibilidad* should be much more, and the point "3.3 *Ocupación de suelo* & *rasante*, respect a fixed *constructibilidad*" verifies that a site coverage of 40% is not always restrictive.

The three-dimensional modelling allows in this case a fast and effective visualization of the problem. It might have been part of the formulation of the norm if it had been elaborated through these means.

Using the three-dimensional modelling as an investigation tool allows identifying the city model beneath a regulation. This way, it is possible to evaluate urban and architecturally as city proposal.

This system raises a method possible to be used in the generation and evaluation of the regulations. It also allows managing the problem of the obsoleteness and lack of dynamism of these.

This way, the urban effects of a norm can be evaluated spatially, before being validated, or, in an inverse way, create a norm stain from the form.

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Photogrammetry and 3D city modelling

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Abstract

3D city modelling and urban visualization using the technology of photogrammetry is one of the largest growing research topics in digital architecture. There are many different methods of 3D city modelling and many different applications of 3D city models. This paper introduces a modelling method of creating a 3D city model from aerial images using a commercial off-the-shelf photogrammetry tool and discusses the efficiency and effectiveness in terms of time, labor, and reusability. The 3D city model is created not only for scientific visualization but also for architectural design evaluations. In this project, a 3D city model of downtown Phoenix, USA, is demonstrated.
Keywords: photogrammetry, city modelling, computer graphics, GIS.

1 Introduction

Recently 3D city models are utilized in various fields such as scientific visualization, 3D maps, car-navigation systems, 3D-GIS, and 3D games. In this paper, *3D city model* is defined as a digitalized three-dimensional computer model of an existing city rather than a virtual city model. There are many different methods for creating 3D city models, and researchers are trying to develop more efficient and effective methods. These modelling methods are mainly categorized into three approaches; automatic, semi-automatic, and manual. The automatic approach is to extract 3D objects such as buildings, streets, and trees from aerial or satellite images by using the technologies of image process and pattern recognition in artificial intelligence [1, 2]. The Semi-automatic approach is to create 3D objects one by one with the support of technologies like photogrammetry and 3D vision [3]. The manual approach is to create all geometries of an object one by one in CAD and CG software packages

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that are commercially available such as 3D Studio Max and Maya. Spine3D [4] is one of the well-known CG design companies that develop 3D city models manually.

The methods of 3D city modelling also vary from available resource. LiDAR (Light detection and ranging) and Photogrammetry are the technologies commonly used in extracting 3D geometries. The LiDAR instrument transmits light to a target and measures it by using the reflected signals. There are two approaches in using LiDAR. One is to acquire the LiDAR data from an airplane. This is commonly used in remote sensing for creating digital surface model (DSM) and digital terrain model (DTM). Another approach is to get the LiDAR data from the ground and extract the complicated geometries like architectural components and civil structure [5]. A set of points extracted from LiDAR is converted into polygons. This makes it possible to obtain very details, but it requires researchers to fly or walk over to get the necessary data.

Photogrammetry is the other solution. Like LiDAR, it can be used for both aerial and ground images. Aerial images are used to extract abstract forms of buildings, and the ground images are used to extract their details. Nverse Photo [6] and Shape Capture [7] are the example commercial software packages for 3D modelling that use photogrammetry.

2 Classification of 3D city models

Choosing the most suitable method for creating 3D city models depends on given resources and objectives of using them. The given resources are based on time and labor, and the objectives are on quality and scale. 3D city models are categorized into 9 classes based on quality and scale in Table 1.

Table 1: 9 classes of city models.

	Low Quality (Online Quality)	Middle Quality (PC Quality)	High Quality (Movie Quality)
Street Level	SL	SM	SH
Block Level	BL	BM	BH
City Level	CL	CM	CH

There are three scale categories; *Street Level, Block Level, and City Level.* The *Street Level* model is used to visualize a street with buildings and landmarks, such as trees, traffic lights, signs, and bus stops, from human's views. The *Block Level* model is to visualize street blocks in a city including buildings and landmarks form bird's eye views. The *City Level* model is to visualize a whole city from airplane's views.

In addition to the classification based on scale, the 3D city models are classified into 3 quality classes; low, middle, and high. The low quality model is designed to render interactively in real time on Internet browsers, the middle quality model is to render in real time on PCs, and the high quality model is not for interactive rendering but for static rendering. .

1) The Street level and low quality model (SL) is the model with buildings and landmark components without any textures or materials. The model is usually used for evaluating the height and volume of buildings from views of human. Usually it is seen at the beginning phase of design in architectural design studios. The model is created with commercial 3D computer graphics software packages such as FormZ [8] and SketchUp [9].
2) The Street Level and middle quality model (SM) has more details and textures than SL. Many of the 3D game models such as DOOM3 [10] is classified into this model. In order to visualize the model interactively in real time, the details are created with minimum polygons. With the improvement on graphics cards, very realistic images can be rendered with high-resolution textures even without details.
3) The Street Level and high quality model (SH) is the highest quality model and seen in architectural presentations and Hollywood movies. Since it is necessary to create 3D objects one by one using CG packages, it takes a lot of time and labor. The images are very realistic and beautiful, but it cannot be rendered in real time.
4) The Block Level and low quality model (BL) is used for visualize street blocks in a city. Since a model usually have hundreds of buildings, each building should be represented as a simple volume without any textures in order to render them in real time. Google earth is one example that shows this model in 3D views [11]. 3D-GIS model with digital terrain model (DTM) and 3D buildings, which are created by extruding 2D polygons with building height values, is classified into this class as well.
5) The Block Level and middle quality model (BM) is an upgraded model of BL with textures for buildings and ground. The ground object has textures based on the ortho-images. Many automatic approaches have been researched and developed for creating models in this class using the photogrammetry and image processing technologies [12].
6) The Block Level and high quality model (BH) is based on BM, and a little more details are added to each building. The model is usually used for static rendering because it is too heavy to render the model interactively in real time. A model of 1930’s New York City used in the Hollywood movie “King Kong” [13] is the typical example of this class.
7) The City Level and low quality model (CL) shows only DTM mapped with ortho-image without buildings, street, or landmarks.
8) The City Level and middle quality model (CM) has DTM and buildings without textures. Each building is represented as a box.
9) The City Level and high quality model (CH) has DTM and buildings with textures.

3 3D city models using photogrammetry

Photogrammetry is one of the technologies most commonly used in 3D city modelling. By using it, the attributes of object are extracted automatically from multiple images. There are two approaches for photogrammetry. One is to use photos taken from the ground. An advantage of this approach is that taking photos does not cost much. On the other hand, there are some disadvantages. 1) It is difficult to take photos of building from backsides because of security and privacy issues. 2) Since it needs to take several photos to cover all elevations for each building, it is necessary to manage a number of image files. 3) It is difficult to match the two images with different white balances on the same building. In short, the approach using ground photos is useful for extracting building geometries when the more details are required such as for SH and CH models, but it needs more time to manage and fix the textures.

Another approach is to use aerial or satellite images. It is advantageous because it needs only a few images. Since the textures of buildings are extracted from the same image, the color balances of image are not required to fix. One disadvantage is that it costs more to take aerial photos than ground photos.

4 Problem statements

There are many different methods of 3D city modelling, and there are many different applications using 3D city models. Therefore, it is important to choose the most suitable method for a specific application. In this paper, the most efficient and effective modelling method is defined as the one in which the reusable model in the most various applications is created in minimum time and with minimum labor. In other words, it is more effective and efficient if a model can be reusable among the classes in Table 1, and it is better if a model is created with less time and cost.

5 Methodology

The method of creating 3D city models from aerial photos using photogrammetry is used in this project. The reasons why this approach is chosen is that it seems to be able to create a model that can be used in 8 classes (SL, SM, BL, BM, BH, CL, CM, and CH). Another reason is that it seems possible to finish modelling in a few days after taking aerial photos.

The processes of taking aerial photos, scanning images, extracting buildings from the images, and editing 3D objects are explained as follows.

5.1 Aerial photo and scanning

The most important point in creating 3D city models from aerial photos is to acquire high quality aerial photos, because they affect textures of buildings.

In this project, several different kinds of aerial photo were investigated to find the best aerial photo. Two different cameras were tested. One was Canon Eos-1Ds Mark-II [15] that could take the highest resolution image among the digital cameras commercially available. The images were shot from 6000ft altitude by airplane and from 2000ft altitude by helicopter. In the flight, an aerial photographer held the camera and took images manually.

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In addition to Canon Eos-1Ds Mark-II, a regular aerial photo camera for 9" x 9" negative films was used to take the photos from 6000ft altitude and from 10,000ft altitude. The camera was fixed on the airplane, and a pilot released the shutter.

As explained in Table 2 below, the image taken from 6000ft altitude using the regular aerial photo camera was the best for this project. The other images were not good enough because the side images of buildings were not clear enough to use for the building textures.

In order to take clearer images of textures for the side of building, it is necessary to take several oblique shots in addition to the vertical shots. The flight path for taking regular stereo-pair aerial photos is usually straight as shown in the left image of Figure 1. However, in order to take several oblique shots of the same target, the airplane needs to fly over the same position repeatedly as shown in the right image of Figure 1. In addition, the pilot needs to release the shutter for each shot looking at the screen monitor in order to check the position of target in the image, and the photos are taken during a circulate flight. The pilot needs to be skilled in order to get the proper oblique aerial photos. Three flights were made for this project since the first two were failed because of an inexperienced pilot.

Table 2: Aerial photo.

	6000ft Film	10,000ft Film	6000ft Digital	2000ft Digital (Helicopter)
Pros	Best quality	Cover 3x 3 miles	Easy shot	Easy shot
Cons	Need an expert pilot	Low quality	Blur images	Blur images Many images

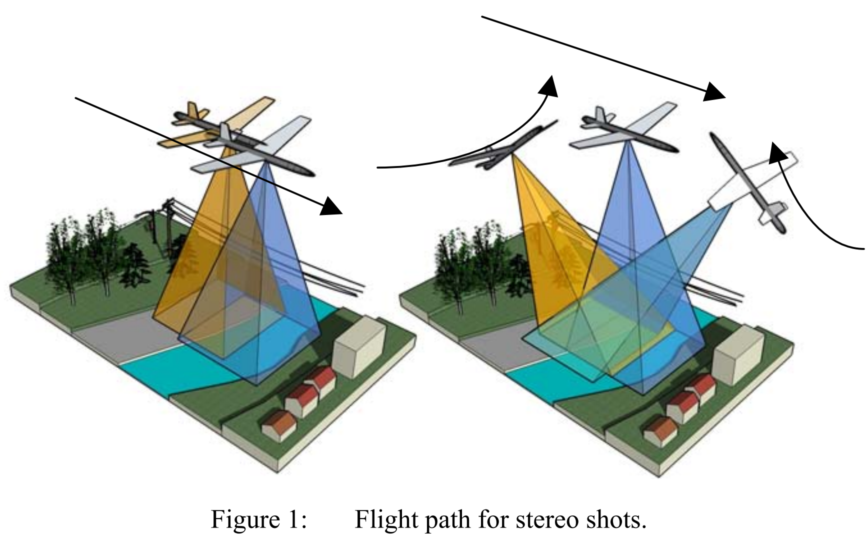

Figure 1: Flight path for stereo shots.

Figure 2: Aerial images scanned with 2000dpi.

Each aerial photo is scanned with 2000dpi, and saved as TIF formatted image without any compression. Each scanned image has about 18,000 x 18,000 pixels as shown in Figure 2.

5.2 Modelling process

Nverse-Photo 2.7 [6], one of the commercial off-the-shelf photogrammetry tools, is used to extract 3D buildings and the ground from aerial images. First of all, the following camera parameters are defined for stereo matching. (1) Calibration Focal Length = 152.884mm. (2) Lens Distortion is input as,

$$K_0 = -0.2877 \text{ x } 10^{-6}, K_1 = 0.8168 \text{ x } 10^{-8},$$
$$K_2 = -0.4265 \text{ x } 10^{-22} \quad K_3, K_4 = 0.0000$$

(3) The scanning resolution is 2000 dpi. (4) X and Y offsets are defined using fiducial marks.

Once the camera registration is completed for all aerial images, the stereo matching process is done. After the matching process, each building is created by drawing polygons on all images. For example, a polygon is created in the first image, and it is sent to the second image. The user needs to edit the polygon in the second image corresponding to the building. This process defines the height and form of the building. By repeating this process, the geometries of building are defined, and the textures of building are automatically assigned from some parts of aerial images. The ground is defined by inputting the ground truth points with the information of latitude and longitude instead of polygons. The texture for ground is also generated automatically.

The model is saved as a 3DS formatted file, which is one of the most common 3D formats. In order to visualize the model at 3D stereo theater, the model is converted from 3DS format to OSG [16] format. Figure 3 shows the workflow of this project.

5.3 Editing 3D model

Autodesk 3D Studio Max [17] is a professional 3D computer graphics modelling and rendering package. The package is used for editing the buildings when they have some problems on their textures. If some parts of building are not visible in some images, the texture are distorted or not generated. In the case, the images taken from the ground can be used to fix the problems. UV-mapping, which is one of the most advanced techniques commonly used in developing 3D games, is applied to edit the side images of buildings as shown in Figure 4. It is not recommended to use heavily because it takes a few hours to fix the problems on each building.

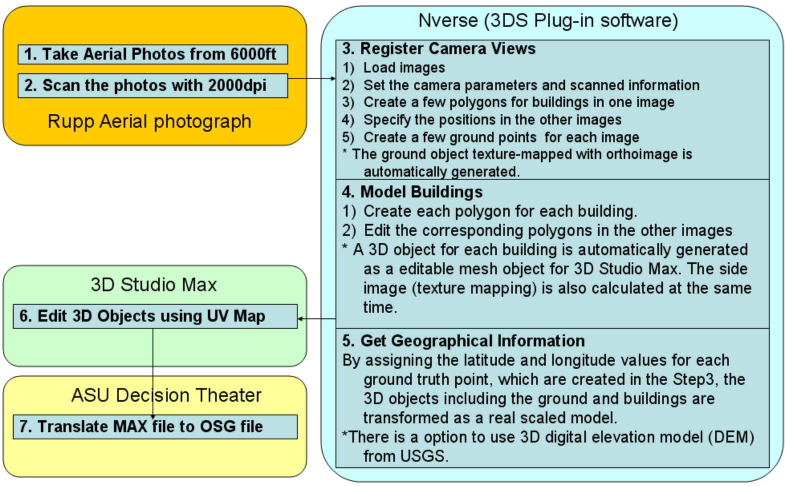

Figure 3: Modelling process.

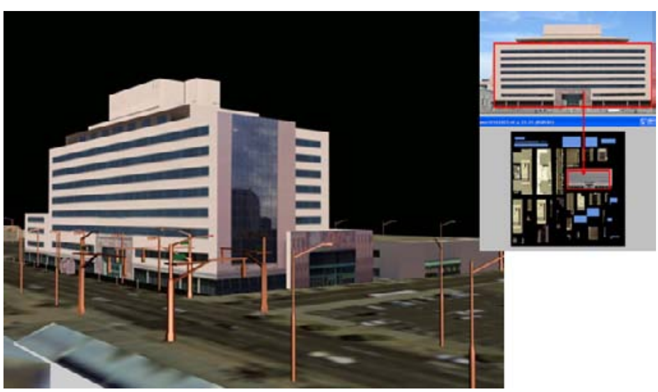

Figure 4: Editing buildings.

6 Results and application

6.1 3D city model of downtown Phoenix, AZ

Figure 5 shows the model created in this project. The model covers about one square mile (1.6 km x 1.6 km) area in the center of downtown Phoenix with more than 700 buildings. The model was created within 16 hours by one person.

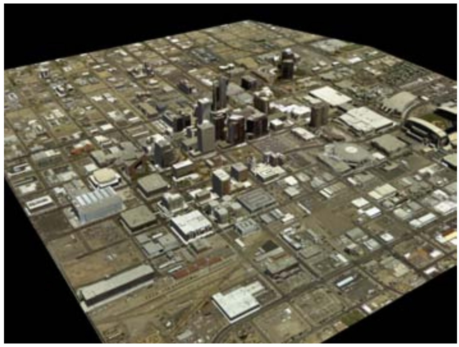

Figure 5: 3D city model of Downtown Phoenix, Arizona in US.

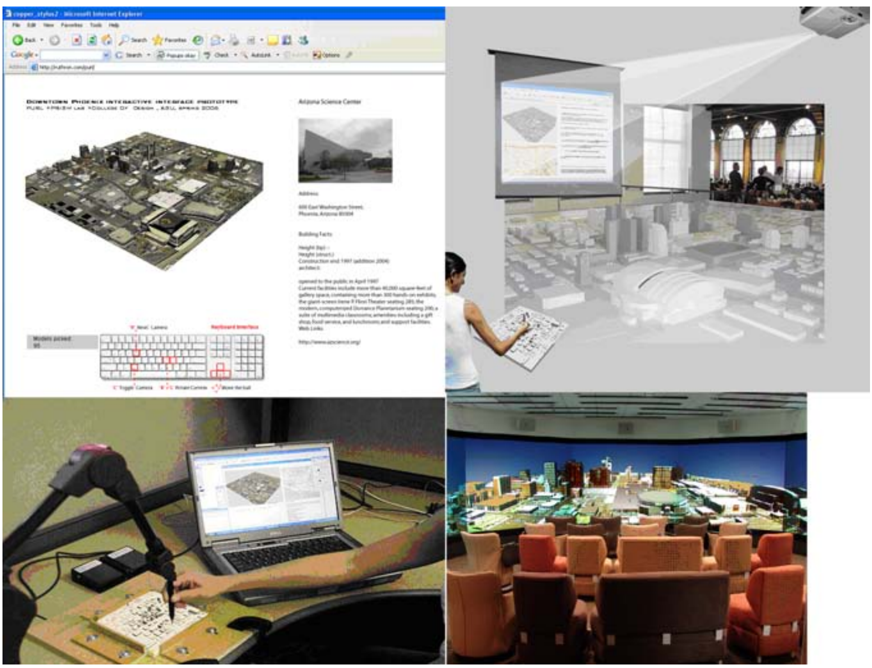

Figure 6: Application of 3D city model; (1: left top) Online application, (2: left bottom) Tangible interface, (3: right top) Physical model, (4: right bottom) VR model.

6.2 Application of 3D city model

Four applications that used the 3D city model of downtown Phoenix was created and demonstrated in Figure 6. (1) The left top image in Figure 6 shows the online web-3D application using the model (www.ruthron.com/purl). The user can change the views and get the information of buildings on Internet browsers.

(2) The left bottom image demonstrates the application of 3D printing. By using the device [18] to get the XYZ position on the physical model, the building information is displayed. (3) The right top image is the conceptual image to integrate the application 1) and 2) with a big 1/32" physical model. (4) The right bottom image shows the scene of visualizing the 3D city model in a VR environment.

7 Conclusion and future work

The followings are demonstrated in this paper.

- 3D city models were categorized into 9 classes based on the scale and quality.
- Several different aerial photos were examined for creating 3D city models with photogrammetry, and the regular 9" x 9" film scanned with 2000 dpi got the best result.
- The modelling process of 3D city model using the technology of photogrammetry was explained step by step.
- 3D city model of downtown Phoenix covering about one mile square with more than 700 buildings was created within 2 days after taking aerial photos.
- Four applications that used the 3D city model of downtown Phoenix were introduced.
- The future work is to implement a computer-based tool for generating more details with the support of photogrammetry in order to make use of the model for SH (Street level and high quality) class.

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Ready, aim, fire: legitimizing the gaming environment

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Abstract

The digital gaming industry, perhaps to the chagrin of the architectural community, has become the epitome of modern business success, drawing in remarkable profits while leading a quiet revolution in youth culture. The systems that have become available in the last several years are sophisticated enough to not simply hint at virtual reality, but rather establish a surprisingly convincing world into which the participant is immersed. These effects are so stimulating that individuals engaged in a first-person shooter combat arena respond physically to the digital simulations, ducking and crouching with comical evasiveness to the virtual projectiles being launched at them. Given the spatial realism being achieved, one would expect that the architectural profession, identified with the crafting of space, would readily embrace these technologies, but the opposite seems to be the case. These environments are viewed as distractions with little value beyond entertainment, with minimal significance in the domain of critical space. The on-going research attempts to bridge this theoretical gap between architectural discourses on spatial perception and the fascinations of virtual immersion. The simulations of digital gaming are too profound to be dismissed, offering tremendous potential as critiques of digital culture, as well as exposing the sensitive underbelly of societal norms relative to the digital interface. While in no way attempting to act as an apologist for the gaming industry or its fixation with the grotesque, a critical examination of its spatial character brings to light an array of architectural origins, both theoretical and spatial. To this end, the fundamental tenants of game space finds resonance, or perhaps dissonance, within the most cherished of architectural experiences, and perhaps begins to devalue architectural poetics by collapsing the importance of physical time and space, making spatial simultaneity possible within the virtual seductions of the screen.
Keywords: immersive environments, architectural representation, digital critique, labyrinths, Piranesi.

1 Introduction

> *"Because what does not correspond to any mathematical law is the arrangement of the openings. Some rooms allow you to pass into several others, some into only one, and we must ask ourselves whether there are not rooms that do not allow you to go anywhere else. If you consider this aspect, plus the lack of light or of any clue that might be supplied by the position of the sun (and if you add the visions and the mirrors), you understand how the labyrinth can confuse anyone who goes through it, especially when he is already troubled by a sense of guilt. Remember, too, how desperate we were last night when we could no longer find our way. The maximum of confusion achieved with the maximum of order: it seems a sublime calculation. The builders of the library were great masters."*
> *– Brother William of Baskerville: The Name of the Rose* [1]

Mankind's reverent infatuation with labyrinthine space is long standing and complex, stretching the expanse of both time and distance. The relevance, if not necessity, of these twisting, fractured and disorienting spaces is so deeply imbedded within the human psyche that the conceptual basis is no more than rumination, reinvented with each subsequent generation as a new metaphorical veil, draped across an original spatial structure. The metaphors of the labyrinth have been chronologically transient, shifting with the cultural needs, whether those needs be theological, aesthetic or experiential. Yet it is the physical structure that has persisted intact, an underlying architectonic skeleton of space and form that provides the formal order, the spatial logic, and the rationale of occupation onto which, or from which, meaning can be derived. The labyrinth exists as series of dualisms, simultaneously a construct of physical and intellectual realms, informing and informed by the occupant, and shaping and shaped by the transcendental experience.

2 Labyrinth as artefact

This question of experience becomes integral to the perception of the labyrinth. Its historical significance within western traditions is bound within a number of theological/mythological braids, first offered within the well-tread stories of King Minos and the Minotaur. Based off of Ovid's version of the story, the origin of the Minotaur and its subsequent imprisonment within the labyrinth starts with Pasiphae, wife of the king, who, during the siege of Athens by Crete, falls in love with a bull, and with the assistance of the inventor Daedalus consummates the adulterous relationship, giving birth to the Minotaur. With the return of King Minos, who is infuriated with his wife's infidelity, Daedalus is commanded to construct the labyrinth, a maze so complex and disorienting that none who ventured into it would find escape (including Daedalus). Human offerings were made to the Minotaur, tributes of the defeated Athenians. One of these sacrifices was Theseus, son of King Aegeus, who had charmed King Minos' daughter, Ariadne. Ariadne, out of her love for the young Theseus, gave him two gifts to help him solve the labyrinth's spatial riddle and slay the Minotaur. The first gift was a ball of pitch, to be lodged in the Minotaur's mouth, and the second was a ball of thread, allowing Theseus to retrace his steps through the bewildering maze. Upon Thesues' escape, and subsequent retreat to Athens with Ariadne (whom he left en route at Naxos), King Minos imprisons Daedalus and his son Icarus within the labyrinth. Daedalus then crafts wings of feathers and wax for he and his son, by which they can escape the labyrinth. However, Icarus fails to heed his father's warnings of flying too close to the sun, and the wax on his wings melts and Icarus plummets to his death [2, pgs 11–13].

While the myth of the Minotaur is far more complex that this abbreviated version, and carries a number of variants, the basic premise of the physical labyrinth as an indecipherable and inextricable linkage of chambers and passage ways was geometrically codified (literally within the continuation of the myth with Daedalus crafting the labyrinthine story into the doors to the temple to Apollo at Cumae). It is this physical impression of the labyrinth, this canonical spatial palimpsest, which has proven the most enduring. Though there is a considerable lineage to the myth, and its transmutations into other similarly crafted narratives (such as Dante's inferno or the biblical accounts of the life, death and resurrection of Christ), the physical form has become an enduring symbol and spatial ordering device likened to the most basic levels of the claustrophobic confinements and redemptions.

This is quickly notable in the medieval labyrinths so often associated with the gothic cathedral, though labyrinthine patterns are found with equal frequency as turf pathways or passages within gardens. While much scholarship has been spent on the interpretations of these woven graphical patterns, an exact understanding of their social or religious meaning is still clouded. The oft-cited notion of the church maze acting as a surrogate for pilgrimage is heatedly debated and compelling alternatives have been offered. Penelope Reed Doob offers tremendous insight into all aspects of the labyrinth, dismissing the pilgrimage metaphor as unfounded, favouring two more plausible alternatives, which combine to a form a third. As Doob states,

> *"So far, then, we have established two medieval reasons for placing labyrinths in churches: as a sign of the enclosing cathedral's magnificence and the architect's genius, and as a sign of hell made extricable through the labors and unicursal footsteps of Christ-Theseus – a sign of redemption as well as a warning to those who do not follow Christian doctrine."* [2, pg 128]

While Doob's arguments continue with great depth and unravel a number of nuances and linkages between the labyrinth, other gothic patterns and tectonic expressions and their corresponding significance to medieval Christian worship, it is her discussions of the dualities of the labyrinth that find the most lasting resonance. Doob brings to light the two primary structures of the labyrinth, one being singular in path and requiring only persistence for navigation (unicursal), and the second being composed of multiple points of decision and direction, within which no one singular path exists (multicursal). While the unicursal model is most often employed as a symbol, both labyrinthine orders are equally latent with a number of diagrammatic dualities.

> *"A diagrammatic labyrinth paradoxically clarifies its own confusion; it holds structural design and the psychological tensions created by that design in perfect equilibrium, suggesting order in chaos, the purposefulness of apparent aimlessness, unity controlling multiplicity."* [2, pg 61]

It is this sort of duality that makes the labyrinth eternal, for while the specific societal meanings have shifted and been displaced, the intrigue of labyrinthine space is perpetuated as a collection of physical simultaneities, of order and disorder, of lucidity and confusion, that beckons the darkest realms of the human consciousness to re-emerge as new and meaningful forms, with its most recent (and perhaps most spatially complete) manifestation within the immersive environments of digital gaming.

3 Labyrinthine gaming

To better grapple with these types of spaces, a bit of clarification is required, not only to offer the historical development of game space, but also the specific emphasis on first-person shooter immersion within the broader field of gaming strategies. Video gaming is commonplace within popular culture, both as part of a mature demographic whose adolescent lives served as the initiates to early video games and the subsequent generations who see these two-dimensional gaming methods as purely infantile novelties within the ever-more complex genre of computer gaming. While games such a Pong and Asteroids were seminal in the linage of game development, their conception of space is highly limited, perceived only as a two-dimensional graphic on the screen through which the player interacts. Though the many variants of these early games are more akin to the novelties of the multicursal labyrinths and mazes of childhood, even at this stage, the notion of labyrinth begins to become ingrained as a spatial strategy. Digital suggestions of walls and barriers, as well as maze-like configurations begin to appear, most notably within the series of games initiated with Pac-Man. This game, and the phenomenon that surrounded it, was all consuming as an interactive device. The infinite manifestations for negotiating the various levels produced more than occasional amusement. It founded a society of sorts, structured around the solving of the spatial puzzles (hints again back to the Cretan myth and Theseus' ball of thread), completing that sought-after "high score" title through the graceful and fluid avoidance of menacing monsters (themselves quite endearing, appearing more like personified rag mops), and more importantly, the rejection of the exterior world.

The evolution of this early labyrinthine strategy has become quite far-reaching, though one particular game offers a definitive link to the present day scenario of first-person shooter gaming platforms. The game *Castle Wolfenstein* was a rather clumsily composed maze game, complicated with a rudimentary storyline by which the maze was to be negotiated. In its most basic state, the narrative and maze worked in tandem, forcing the avatar or character to work through a series of adjoining but concealed chambers, avoiding or eliminating the computer sentinels that monitored each chamber, to arrive at the final destination. Upon eliminating the final sentinel (in the case of this World War II narrative, the fuehrer), the player would then need to retrace his steps out of the maze before being captured. The clumsiness of the movements and the restrictions of planar space offered little more than mild amusement for the digitally savvy adolescent, but its lineage proved far more fruitful. During the years between the creation of *Castle Wolfenstein* and its offspring *Castle Wolfenstein 3D*, the notion of first-person shooter gaming systems was sewn.

4 Virtual immersion and the first-person shooter

First-person shooter games are set on the premise of two basic strategies. On the more technical side, the logic of spatial development and representation is driven by the requirements of real-time animation, which requires a constant updating of the digital environment with each successive movement within the space. The second premise is more ingrained within the notion of the simulation, which is the fundamental point of reference, or position of the eyes. Nearly all games prior to the first-person shooter strategy had operated off of orthographic conventions of plan or elevation, defaulting to the overhead logic of Pac-Man, or elevational presentation of Donkey Kong. The first-person shooter strategy placed the player directly into the space, the screen becoming the virtual eyes of the character's head. This shift in strategy revealed an entirely new set of opportunities for gaming interaction – an enlightenment not dissimilar to the introduction of perspectival representation at the dawn of the renaissance.

Castle Wolfenstein 3D was the first foray into the FPS system, though it was essentially structured off of a similar narrative and spatial sequence as its predecessor. The player navigated a sequence of interlocked rooms and halls, eliminating all of the demons encountered along the way. While equally rudimentary in its spatial definition and means of navigation, *Castle Wolfenstein 3D* (pioneered by id Software) found immense success with the spatial experience and simulation of movement and occupation. The player's movements and lines of sight were freed from the static and detached character of 2D game, allowing for the freedom to look, wander (and become further disoriented) within the spatial immersion. The player was in full control of their avatar, and thus the visual experience as presented to the screen. The 2D gaming methods, with their global and easily mapped presentation couldn't offer the same levels of concealment or intrigue because the absence of foreground and background. FPS suddenly revealed a navigable panorama of space to the player, to which the frontal view was privileged as seen through the eye, but with an equal awareness of the space to the player's back. The labyrinth was still the underlying means of ordering the spatial layout, though the perception of it was no longer planar, migrating away from the graphical mazes of childhood in favour of the spatial play of the Victorian garden mazes or folk crop-field mazes of the rural America.

The current assortment of FPS games is far too numerous to attempt a discussion of labyrinth, spatial perception and sensory engagement for each platform, but it is possible to illuminate the commonalities and underpinnings of each, particularly as spatial representations of the labyrinth. As the forefront of this discussion should be the question of the FPS platform proper. The structure of *Castle Wolfenstein 3D* was fundamentally narrative in both story and space, offering an itinerant experience that helped to organize the game play, which upon first pass was enthralling, but with successive play became predicable and ordinary. Drawn out of its foundation, however was a new pair of games, *Doom* and *Doom 2*, which offered an enhanced narrative play and spatial character, as well as introducing the possibilities of the multiplayer game play. While the original narrative game structure was limited to a single player, *Doom* allowed for the possibility of multiple players interacting within a single digital environment, either as team members working towards a common goal (a kin to the narrative model), or more seductively as equally matched opponents within an arena. No longer was the sole user reliant upon the artificial intelligence of the gaming engine to offer the competition, but rather the established competition through the direct interaction with another player, or group of players, distant in physical space, but immediately present within the digital realms of the FPS game environment. The tremendous success of arena games let to an entirely new method of game strategies, and a corresponding shift in the nature of the spatial environment within which the game play was to unfold. This method of gaming has quickly become the dominant product offering. While the narrative approach has remained as a consistent ingredient to the game systems, nearly all FPS games now offer arena play as a component if not the singular focus in games such as *Quake Arena* or *Unreal Tournament*.

This strategic shift within the industry has been ongoing, and runs parallel with equally provocative developments within the rendering engine itself. The level of realism and detail has become remarkable for the avatar's physical motion and control as well as the material environment in which they are immersed. Early version of FPS movement had the head/eye position locked into a singular horizontal plane, rendering the player unable to look up or down. New character mobility now offers flexible eye and head movement, as well as crouching, jumping, crawling, and any number of other specific body motions. Corresponding developments in spatial rendering have occurred, offering increased material detail, variation and model complexity and well as a host of other dynamic environmental characteristics, such as the play of light and shadow within a space, simulated material tactility (flowing fabrics), degrees of transparency and/or opacity, reflections, queued audio, as well as a number detailed refinements and subtleties, ranging from weather effects to material engagement and response.

5 Piranesi's ghosts

The foundations for these spatial strategies are still fundamentally rooted within the taxonomy of the labyrinth, but the spatial character has moved away from the simple limitations of planar movement. The new game environments are heavily labyrinthine, but more in the spirit of the classical narrative descriptions of the Cretan labyrinth, latent with interwoven paths and chambers, from which the most immediate product is of confusion and disorder, with no entrance disclosed and little or no exposure of a broader surrounding landscape. To this end, these digital spaces, so heavily interlocked with paths and discrete vantage points that appear inaccessible, bear a striking resemblance to the *Imaginary Prisons* etchings of Piranesi. This is not without surprise. Piranesi's visions of the dungeonous volumes graphically capture both the literary description of the classical labyrinth of myth while also providing and ideal perspectival template for the arena gaming. His conceptions are heavily imbedded with scalar shifts and dimensional ambiguities, of soaring passageways to and from undisclosed origins, all of which entice the eye to wander, but offer no means of orientation – thus returning to the one of the many dualities of the labyrinth itself. As Marguerite Yourcenar noted in her essay "The Dark Brain of Piranesi,"

> *"No connoisseur of oneiric matters will hesitate a moment in the presence of these drawings evincing all the chief characteristics of the dream state: negation of time, incoherence of space, suggested levitation, intoxication of the impossible reconciled or transcended, terror closer to ecstasy than is assumed by those who analyze the visionary's creations from outside, absence of visible contact between the dream's parts or characters, and finally a fatal and necessary beauty."* [3, pg 110]

Yourcenar's observations of the dream state that is incurred by the simple observation of Piranesi's prison sketches are both accurate and visually obvious. The prison sketches are saturated with various degrees of visual intrigue. Outside of the immediate spatial seductions, the spaces are latent with the suggestive devices of torture, along with the quintessential atmospheric characteristics that tapped into all of the senses. Yourcenar's notes these sensory seductions as well.

> *"Finally, this void is sonorous: each Prison is conceived as an enormous Ear of Dionysus. Just as in the Antiquities one hear the faint echo of an aeolian harp in the ruins, the rustling of the wind in the weeds and rushes, here the roused sense of hearing perceives a formidable silence in which the lightest footstep, the faintest sigh of the strange and diminutive strollers lost in these aerial galleries would echo from one end of the enormous structures to the other."* [3, pgs 111–112]

In fact, it is this sensory scintillation, this remarkable ability to transcend the purely visual and to touch on the fullest spectrum of experience that makes the relationship of Piranesi's prisons and the spatial layering of arena gaming so remarkably strong. If Piranesi's imagery creates a dizzying array of sensory suggestions through purely visual methods, the prison sketches are but mere hints of the verisimilitude revealed in immersive gaming. For while Piranesi's spatial movements cannot extend beyond the frozen moment of one specific view, the immersive game environment allows the bewildered participant the freedom of movement, the opportunity to explore the fullest spatial rapture that Piranesi was surely dreaming of. If the stories of the origin of Piranesi's

Imaginary Prisons emerging from illness-induced delusions is accurate, then the first-person shooter game environment is this dreamscape (or nightmare) made physically manifest, albeit within the confines of the digital realm. Yet this digital constriction hardly limits the physical experience. Just as a dog dreaming may physically exhibit the chase envisioned with twitching legs and muffled barks, the participant within the game environment responds to the spatial experiences with distinct physical reaction. No longer does the player remain passive to the stimuli, but is now fully engaged, bobbing and weaving in vain attempts to avoid the various threats of the opponent which is often undisclosed, and almost entirely anonymous.

It is this very character of the game, a re-emergence of sorts of the dualisms expressed in the classical interpretations of the labyrinth and its many narratives, that have drawn their spatial inspiration from Piranesi's space (though perhaps unknowingly). The player within the game is simultaneously protagonist and antagonist within the unfolding story, acting as a direct assault to their opponents from the singularly framed perspectival screen image, fully conscious of their equal and omnipresent position as the target. The soaring spaces and multiple vantage points of Piranesi's sketches provide fertile ground, offering numerous points of concealment and paths for covert movement from which to gaze upon the bounded combat theatre. In fact, at the heights of the game, when the dynamic play rises to levels of frantic movement and evasion, exaggerating the visual enrapture provided by the multitude of passageways and portals, the interwoven volumes that repeatedly turn inward upon themselves, enticing the player into constant motion both visual and physical within a sequence of spaces with no entry and no exit. Yourcenar notes an equal trait in the Prison sketches, which find near-exact replications in the spatial containments of the arena.

> *"Often the arch of a vault in the upper part of the image conceals the top steps of a staircase or the end of a ladder, suggesting heights still loftier than those of the steps and rungs visible; the hint of another staircase plunging lower than the level on which we are standing warns that this abyss is also to be extended beyond the plate's lower margin; the suggestion grows even more specific when a lantern hung almost on a level with the same margin confirms the hypothesis of invisible black depths below. Moreover, the artist succeeds in convincing us that this disproportionate hall is hermetically sealed, even if the face of the cube we never see because it is behind us."* [3, pg 113]

It is this notion of the hermetical seal, of absolute containment that reaffirms the labyrinthine character. The early labyrinths, as both physical and metaphorical operations, are in a constant state of simultaneous expressions/simulations, to which Piranesi and the immersive game environments prove a natural extension. The classical labyrinths of antiquity no longer survive, though their impenetrable brilliances and spatial conundrums are well documented throughout any number of historical texts. Yet, when reading the verbal descriptions, the immediate visual depiction aligns quickly to Piranesi, which in turn flips from the perspectival suggestions of his two-dimensional plates, to the virtual realities through which gaming arenas have found emerged. To be sure, the metaphorical significance of the labyrinthine story still unfolds within the game systems, but its hints at morality and conscience are quickly deflated to the most grotesque levels of amusement. Thus it is the physical construct of the metaphor that has been maintained, as if in some subconscious acknowledgement that the meaning of such stories, or their redemption within the accelerated visual culture of modern society, must be presented within the notion of labyrinthine space itself.

6 Closing thoughts

When looking to the nature of society and its on-going infatuation with the digital realm, it is of little wonder that the Piranesian hauntings within the gaming world are so easily detected. Equally, the application of the labyrinth as a spatial construct for these games seems is not only a convenient and logical extension of the amusement garden mazes, but also hints at a perpetuation of fascinations of the darker realms of the human imagination. Though a great deal of time and effort has been spent on the examination of the physical aspects of the construct, relieving the burdensome chores of exploring of societal meanings of these forms, this sort of reading needs receive a nod of recognition, even if it is somewhat cursory.

The labyrinthine fascinations of the antiquities occurred as a two-fold event in which the physical manifestation was inextricably a part of the corresponding myth. To this end, the physical system of labyrinth, whether as a spatial condition itself or as a graphical representation, was impregnated with an understood societal meaning – to speak of the Chartres labyrinth as simply a geometrical weaving stripped of symbolic significance is absurd. Even if the modern understandings of its significance must rely upon certain approximations or historical interpretations, the knowledge and understanding of society in the classical periods, or more so in the medieval periods make clear that the labyrinthine form was latent with meanings and rituals. Yet, the discussion of game space and its borrowing of the labyrinthine logic suggest that these physical forms have been stripped of this meaning, re-occupied as if the labyrinth is simply a shell for the purest sake of novelty and distraction. However, if the fullest understanding of the labyrinth has perpetuated as a form from the earliest ages of the antiquities, repeated in the imagery of Piranesi and retold in the gaming environment, does this not imply an equal but often overlooked social significance? Yourcenar on again provides some insight into this avenue through Piranesi's visions:

> *"We cannot help thinking of our theories, our systems, our magnificent and futile mental constructions in whose corners some victim can always be found crouching. If these Prisons, for so long relatively neglected, now attract the attention of a modern public as they do, it is perhaps not only, as Aldous Huxley has said, because this masterpiece of architectural counterpoint prefigures certain conceptions of abstract art but above all because this world, factitious and yet grimly real, claustrophobic and yet megalomaniacal, cannot fail to remind us of the one in which modern humanity imprisons itself deeper every day, and whose mortal dangers we are beginning to recognize."* [3, pgs 120–121]

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If, as Yourcenar suggests, the relevance of Piranesi's *Imaginary Prisons* resounds with some prophetic visual speculation of the modern built world, then perhaps the games and the spatial escapism that they offer is equally revealing. The storylines and gaming strategies seem to revolve around the grotesque, often situated within contexts so grim as to align, if not surpass the bestial narratives of the Minotaur, or of Dante's descent into the Inferno. This fixation upon the debased, when combined with the excessive dynamism of the game play and the remarkably charged and disorienting chambers through which it occurs, indicates that the character and stimulation of these virtual realms is far more rewarding than the physical environments that the players can actually engage. To this end, the simultaneity of experience, the otherworldly seductions that immersive gaming environments perhaps offer some level of debased lucidity to a world that is otherwise mired its own banality.

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Comparative navigation system for collaborative architectural design

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Abstract

We investigated the concepts, strategies, and functions of a 3D virtual design environment for collaborative, real-time architectural design using our 3D comparative navigation system and virtual reality technology. The development of the 'comparison' concept has enabled interactive design in real time in a 3D computer environment. Since participants must be able to easily understand the proposed design, systems that help them gain this understanding are required. While comparison is an effective way to gain such an understanding, comparing one proposed design to another using existing systems is difficult because the user must operate their viewpoints separately. We therefore created a prototype system that displays different contents simultaneously while controlling the viewpoints automatically to facilitate content comparison. This comparative navigation system facilitates the comparison of proposed designs by displaying related parts of the designs automatically. In this paper, we describe the concepts, strategies, and functions of a 3D virtual design environment for collaborative, real-time architectural design that is based on our 3D comparative navigation system and real-time simulation technology. We also evaluate the advantages and disadvantages of using this design environment for collaborative architectural design.
Keywords: collaborative design, comparison, interactive, real-time simulation, virtual reality, digital archive, experience.

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1 Introduction

The use of 3-dimensional computer graphic (3DCG) models as an architectural design tool has have been increasing in recent years. Awareness of design has been increasing, and awareness is essential for efficient architectural rendering and agreement between participants. Both specialists and non-specialists can more effectively understand a design by using 3DCG.

The inspection of designs by participants and the demand for presentations are high. Various viewpoints need to be considered in collaborative design, not only the viewpoints of the enterprise body or designer. There is also an increasing demand for designers to be able to respond immediately to demands in presentations.

Collaboration up till now has involved the creation of still pictures or animations from a viewpoint assumed in advance. But it is difficult to guess all the assumptions for all the needs that the participants. Moreover, during collaboration responses cannot be immediately made to spontaneous needs.

Here we focus on a 3D real-time simulation engine as a design tool that solves these problems immediately. It would provide an effective, interactive, and rapid design platform. It could be applied to all stages of the design process and be used to check the designs at any time, anywhere, and at any stage. Its support of visualization and interactivity would enable good communication between the client and designer, thereby reducing misunderstandings. The real-time interactive previews it would enable should become a major part of the design process.

The rapid increase in the power of personal computers along with the drop in their prices has led to the migration of visual simulation and computer animation applications from expensive workstations to inexpensive PCs. We can now obtain faster rendering and higher quality results from PCs. The development of 3D real-time visual simulation has enabled the rendering of high-quality images at high speed.

Architectural design involves two major components, i.e., photorealistic and scenario scripting, which enable participants to feel a greater sense of realism. In the field of entertainment, movie makers and video-game programmers are investing a great deal of economic and human resources in developing a good interactive interface, i.e., a 3D real-time simulation engine. The entertainment field is expanding very quickly. This field has grown considerably over the past few years, and hardware and software are approaching perfection.

The aim of our research was to develop a good, interactive 3D development platform. It arose from an urgent need for 3D real-time simulation techniques that could be used to produce better architectural designs. We therefore focused on applying a real-time simulation engine to architectural design.

1.1 Comparison for collaborative design

The participants in a design project must understand the proposal on which they are working. Systems that help them gain this understanding are therefore required. Comparison is as an effective method for assisting understanding. For example, the representation of a person can be compared with that of an object to help the user better understand a certain object. By considering the differences, the user can recognize and understand an object. That is, the user compares and contrasts to clarify the areas with similarities and differences, enabling the user to recognize each similarity and difference. Therefore, we put considerable emphasis on comparison. A person can clarify the correlation, the effect, and the causal relation of objects by multilaterally comparing the objects. In addition, a person can deepen his or her understanding of each feature of the contents being compared, resulting in a better overall understanding of the whole.

Comparing one type of content to another using existing systems is difficult because users have to locate contents and observe them from separate viewpoints. With this in mind, we developed a prototype system that simultaneously displays various types of content while automatically controlling the viewpoints, enabling the user to easily compare them. Such a comparative navigation system facilitates comparison of design proposals by displaying their related parts automatically. Our 3D comparative navigation system is semantically a 3D extension of such a system. In the real world, people can walk through only one space, while in virtual space, a user can walk through many spaces at the same time. This is a key concept of our system, and it is intuitive and effective.

1.2 Digital archives for comparison

Early digital archives only digitized and stored text and photographs, while modern digital archives now include photographs, videos with text explanations, and 3DCG models. In the architectural field, for example, the use of 3D digital models for computer-aided-design/computer-aided-manufacturing has improved the efficiency of design, construction, and management. The 3D model can be of huge objects that one can walk around, such as places with historical architecture or archaeological sites. The digital archives described in this paper assume a 3D model, hence the term ‘3D digital archives. ’

Many case studies reflecting the expansion of 3D digital archives have been presented at international conferences [1–4]. The main focus of these studies has been the construction of the archives. There have been few reports of research into how such archives can be used or how they can be experienced.

The main feature of 3D digital archives is that users do not simply see a flat 2D image of the contents out of context – they can see the contents from all angles in a natural setting. In addition, users can experience the contents as if they were in the real world. Moreover, they can run simulations and scientific investigations that would not be possible in the real world.

2 Navigation function for comparison

To gain an understanding by comparison, we need to consider the original purpose and objective first. The content to be used changes on the basis of the comparative purpose and comparative object.

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We have been examining various types of comparisons used in design projects over many years. The comparisons were made using various media, such as real-time simulation, animation, and still pictures. The functions required for comparison navigation were extracted by examining the comparison techniques used in the design projects. To generalize the comparison techniques and make them suitable for sharing, we arranged the main contents used for the comparisons on the basis of two viewpoints.

- Comparison of the differences in existence, form, and size to reveal the identity, similarities, heterogeneity, and features of 3D structures.
- Comparison of the changes in an object over time to reveal the similarities and differences at each stage, thus giving a picture of the change process.

The functions of comparison navigation were considered based on these two viewpoints. Users can compare different contents to help them understand particular content. By considering the differences, users can recognize and understand the content. They can also clarify the relationships, effects, and causal relations between different contents by comparing the contents multilaterally. In addition, the process of comparison makes it easier to identify different features of the content, encouraging greater understanding. The functions were arranged in accordance with the comparison purpose, the target content, the viewpoint setup, the viewpoint movement, the screen separation, and the content expression. Consequently, ten functions were identified for general comparison navigation; screen division comparison, photograph/model comparison, transparency change comparison, superposition comparison, model change comparison, camera viewing angle change, shadow display, comparison object insertion, measurement, and guide map display.

We developed a comparative navigation system that uses these functions and real-time simulation to facilitate interactive comparative studies of 3D architectural designs.

3 Comparative navigation system

In this section we describe the development of our comparative navigation system for 3D architectural design and our prototype system.

3.1 Development

We used various tools, including an authoring tool, a modeling tool, and an image-editing tool, to develop this system. The main technology used was real-time simulation technology based on virtual reality.

We developed an interface for a real-time simulation system and added it to the graphical user interface (GUI) using Virtools®, which is a Microsoft© DirectX Graphics Application Programming Interface (API) used as an authoring tool in the game development environment. Producing architectural simulation is an impossible task for non-professional programmers, and architectural designers basically have no idea of how to produce a 3D scene. Virtools' building block system was specifically designed to meet the needs of cutting-edge interactive

3D development and is the only interactive 3D authoring tool accessible to non-programmers. Building Block is a subprogram packaged in a dynamic link library.

We assign building blocks in the scene as object behaviors through the visual authoring interface. We can then modify the scene by linking building blocks (using another subprogram). Specifically designed to meet the production needs of cutting-edge architectural simulation, the building block system provides the groundwork and tools users need to unleash their creativity and harness the full potential of the 3D real-time simulation engine. Users can import industry-standard media files to the building block system as 3D models, textures, characters, sets, and sounds. They can attach behaviors to these entities to create interactions. They can control and tweak the behaviors to form a higher-level element that forms the foundation for interactivity or simulation. The building block system's intuitive GUI enables real-time 3D environments to be designed and instantly experienced in an interactive sophisticated manner. Behaviors can be collected from a multitude of sources (libraries, other projects, etc.) and be exchanged over the Web. This system's open architecture makes all the behaviors compatible, so they can be recombined with existing modules. The interface is constructed using Virtools® scripts, as shown in Figure 1.

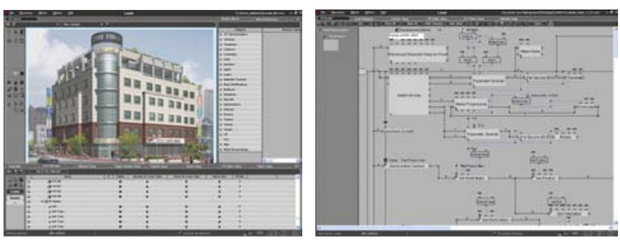

Figure 1: Scripts for real-time simulation interface using Virtools®.

Specifically, we used a note PC with a 4.3-GHz CPU, an ATI Radeon 9800 GPU, and 2-GB RAM. To enable us to perform the rendering in real time with smooth movement, the rendering had to be done at no less than ten frames per second. This system was designed for comparative navigation in collaborative architectural design. The system had to meet three conditions in particular for it to support real-time simulation.

1. *High-speed rendering*: There is a trade-off between a high sense of reality and high-speed rendering as the system may not have sufficient performance for both. Priority was thus given to rendering at high speed to archive real-time simulation. The system also had to ensure the highest sense of reality.
2. *Lightweight 3D data*: One way to increase the rendering speed is by reducing the weight of the data. A balance needs to be found between sufficient data speed and a sense of reality. Moreover, the user should not feel stress while using the system through the Internet. That is, the system should be able to read the 3D data in less than 90 seconds. This can be achieved by selecting suitable hardware and software.

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3. *Easy operation interface*: The interface should be easy to operate. In situations where operation does not catch up with rendering, the rendering speed should be reduced. Moreover, the interface should be immediately usable, even by a first-time user.

3.2 System outline

This system enables a general user to construct a building in virtual space. The internal and external design models for the building are first recorded on the modeling server. If the name of the building that the user wants to access and use for the server for network distribution is already defined, interior and exterior space models suitable for it are retrieved from the modeling server. Moreover, if a design proposal to use it is already defined, the model is loaded from the modeling server and sent to the user. The user can design the proposal while manipulating the model in virtual space. The user can also record the data on the server using his or her ID. The system concept is illustrated in Figure 2.

1. The user accesses the web and selects a model from a menu.
2. The web server sends a request to the database management system (DBMS) for information about the requested model.
3. The DBMS sends the uniform resource locator (URL) of the file server containing the requested information.
4. The web server sends a request to the file server for the target file.
5. The file server sends the requested file.
6. The web server displays the file contents to the user.

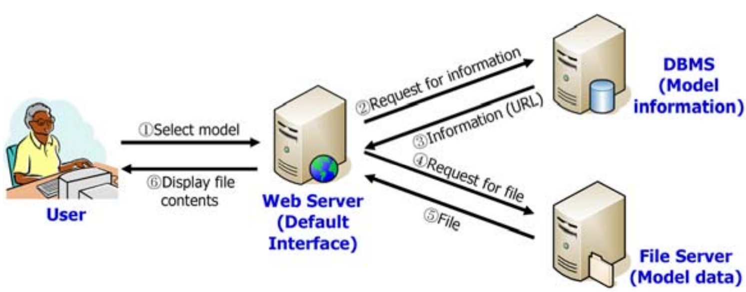

Figure 2: System concept.

3.3 Prototype

The prototype system includes the features of a traditional walk-through simulation and is especially aimed at enabling users to experience the archive information through browsing in the following ways.

- As the use freely walks through the archives, the system provides on-demand comparative views of related content.
- If the user ‘collides’ with a model wall, a collision detection function generates a rebounding effect, similar to the impression received when colliding with a wall in an actual building.

- The user's view is fixed at eye level by a 'gravity' function. The user does not 'sink' into the floor or 'float' above it but rather walks around as in the real world.
- The user can compare the various types of archive contents interactively. As soon as the user selects contents to be compared, the system displays them.
- The user can select from several interfaces – a mouse, a keyboard, a game controller, and a space/mouse traveler.

The process of making a comparative navigation system for a 3D architectural structure experience can be divided into five steps (Figure 3).

1. Gather into a database all data created by the modeling; 3D models, GIS models, photos, etc.
2. Convert the data into models using modeler for Virtools®. Group the models together to form scenes within a circumferential environment setting, a material setting, and alterable models.
3. Assign attributes and behaviors to the objects and scenes in the setting, including the camera settings, light settings, collision detection settings, level of detail (LOD) settings and gravity settings. Also create the GUI and system functions.
4. Test and debug the system using imported 3D objects.
5. Save in the database the behavior blocks, scenes, etc. constructed during testing.

The GUI operates as shown in Figure 4. We optimized the comparison navigation, which is the most important concept of this system, so that it can be fully utilized. For example, to enable many types of content to be compared, we made it easy to switch between one-screen, two-screen and four-screen mode comparison.

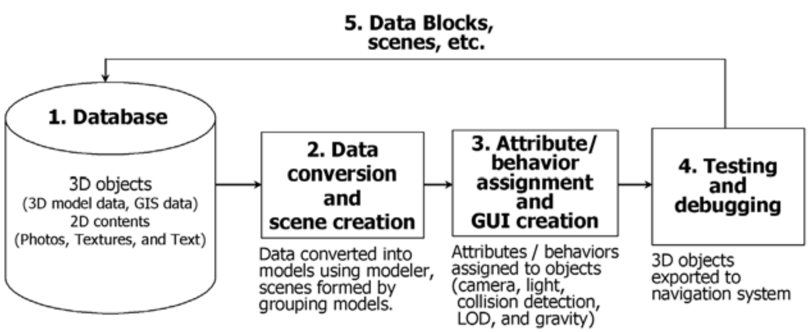

Figure 3: Steps in creating comparative navigation system.

3.4 Functions

The main functions of the system are 3D space move, plug-in, concurrent comparison navigation, and cross-section viewing.

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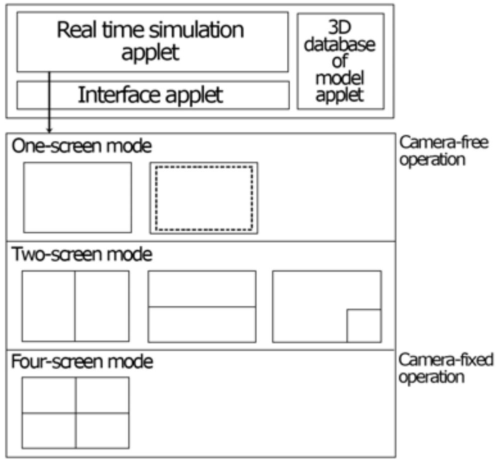

Figure 4: Operation of GUI.

3.4.1 3D space move

The basic functions for moving in 3D space are 'free walk' and 'free flight'. They enable a user to examine a proposed design in 3D space. The user can freely start at any point and move freely in 3D space.

3.4.2 Plug-in

Using a system like that illustrated in Figure 2, a user can choose the data insertion function from a menu on the screen. The system then loads a 3D model that the user chose from the database for the design. The 3D model can be arranged freely. Moreover, the rearrangement is also possible after arrangement, rotation, and scale change.

3.4.3 Concurrent comparison navigation

Concurrent comparison navigation enables the user to comparatively examine a design proposal on one, two, or four screens by using easy key operations. In one-screen mode, the user can compare two proposed plans on the same screen. In two-screen mode, the user can compare two or more proposed designs by dividing the screen, as shown in Figure 4. In four-screen mode, the user can compare a proposed design with a photograph, etc.

One-screen mode

- *Superposition comparison*: The position and size of a structure can be compared by layering two types of content and changing the transparency of one of the layers.
- *Comparison by inserting objects*: Size and scale can easily be grasped by inserting and displaying a 3D object of a known size such as a piece of furniture or a person.

Two-screen mode

- *Vertical/Horizontal screen division*: Users can compare contents while walking in virtual space by displaying two type of contents on the same screen

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simultaneously. The user can then understand the composition of the space through two camera views. The display can be divided between left and right or between top and bottom. A controller that operates both cameras simultaneously is shown at the center of the display. As the user traverses the same route on both screens, each screen displays the content from the appropriate viewpoint.

- *Guide screen mode*: Users can display another proposed design on a small guide screen while focusing on the design of interest on the main screen. The designs can be switched between screens.

Four-screen mode

- *Photograph/model comparison*: Users can select a photograph from a photograph database, and the selected photograph is displayed in the lower left space. At the same time, models with the same viewpoint as the photograph can be displayed in the two upper spaces. Using this function enables the user to simultaneously compare the contents of various media, such as 3D models and 2D photographs. The user can also position the camera at a particular viewpoint.

3.4.4 Cross-section view

Users can display a cross-section view of a structure by controlling the cutting plane. Using this function enables the user to understand the inner structure in detail.

4 Conclusion

In conclusion, as the first step in developing a shared 3D environment that enables users to interact and understand architectural 3D models collaboratively, we have developed a prototype of an interactive navigation system that supports comparison. We have thus prepared the basic technology for experiencing architectural spaces by quickly examining designs through the Internet. Our comparative navigation system equipped with a 3D database makes it possible to use 3D data and comparison functions for various purposes in architectural design. Furthermore, the interactive interface built into the real-time rendering system enables a knowledge-exchange architectural design system to be developed, thus providing alternatives to traditional architectural design systems. By using this system, users can experience 3D contents comparison by quickly examining contents through the Internet.

We plan to expand the amount of content that can be compared by developing a parallel navigation system. We want to develop into a system that can perform various comparison for the purpose. For example, a user could not only compare one type of 3D content to another type of 3D content, but also compare 3D content with a photograph, with a texture, or with a video clip. We also plan to enable temporal comparison in addition to spatial comparison. We are considering enlarging the range of projects that can be analyzed, increasing the amount of data used to set up the model, and speeding up rendering during real-time simulation. A structure is need that displays only the data required to provide an adequate explanation to avoid having to handle too much data and having to provide an overly complicated interface. This should enable more effective presentations for specific purposes, depend on processing efficiency. We also plan to investigate how the experience of presence in a 3D virtual space can be achieved through easy operation of the interface.

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Re-thinking digital design

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Abstract

Designerly ways of thinking have become a significant topic in design research. If indeed, the contemporary phenomena of "digital design thinking" are different from traditional models, then there is emerging pressure to pioneer new teaching paradigms Theories and methods of digital design can no longer be conceptualized as the *merging* of computational tools with conventional formulations of design thinking. Within the framework of this orientation to a critical formulation of new educational agenda, pedagogical issues are considered. A new orientation to understanding the impact of digital media on "digital design thinking" and pedagogy is presented, discussed and demonstrated.
Keywords: digital design, digital architecture, digital design thinking.

1 Introduction

Theories and methods of digital design can no longer be conceptualized as the merging of computational tools with conventional formulations of design. There is the need to pioneer a new understanding of the nature of designing in relation to digital design media. If the very nature of design is radically changing, how then can we accommodate and recognize emerging theories of design as the basis for a new pedagogy? It has now become important to consider the significance of terms such as "digital design thinking" (Oxman [15]) and what they might imply with respect to new approaches of design education. If digital design thinking constitutes a new conceptualization, including concepts as the meaning of form, the nature of functional and formal knowledge in design, and generative processes, then there is a need for a new pedagogy.

The conventional educational model in the design studio generally employs a simulation of praxis as a didactic model. That is, the didactic stages are driven by a theoretical interpretation of program, site and conditions carried through stages

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of conceptualization, schematic design and design development. Furthermore, most studios still employ well accepted knowledge-bases and typologies as well as traditional paper-based sketches as media of what was referred to as a conceptual and explorative medium. Schön's classic characterization of visual reasoning in the design as a "dialogue with the materials of the problem" and the process of "backtalk" from visual images (Schön [17]) are still the dominant model for teaching in the design studio. However, as we attempt to re-evaluate the logic of the Schön model, we find the need to re-define the concept of "material" and to understand the impact of digital design in design thinking.

Designerly ways of thinking have become a significant topic in design research (Lawson [8]). However, if indeed, contemporary phenomena of "digital design thinking" are different from traditional models, than there is emerging pressure to pioneer new teaching paradigms (Kvan et al. [6]). Within the framework of this orientation to a critical formulation of new educational agenda, the following issues are considered:

- Are we encountering new paradigms of design, or are we essentially encountering the same cognitive phenomena of known processes of design thinking in the new digital media?

- Is digital design so different from traditional paper-based design that many of our root concepts must be reformulated? If this is the case, how then, can we begin to conceptualize and formulate "digital design thinking"?

- Furthermore, if conventional teaching approaches are obsolete, what are we teaching when we teach about the design media? Are we, in fact, teaching novel design paradigms?

In the context of an experimental design studio we explore and identify these issues, evaluate findings, suggest and test appropriate new didactic principles. The objectives of our initial experimental studio are to take first steps through a process rethinking many of the root assumptions of current computational conventions. We determine the relevance of these findings for conceptualizing new pedagogy in the design studio, and carried out and evaluated these approaches in a series of experimental studios.

2 Towards a new rationale

The evolution of digital design as a unique field of design endeavor, motivated by its own body of theoretical sources, and a culture of discourse, is beginning to evolve unique ideology, methodologies and formal content (Oxman [15]; Liu [9]; Kolarevic [5]). Given the growing amplitude of issues and subjects in digital design as witnessed by practice, research and education, we need to formulate a theoretical framework that is suitable to the formation of design educational theory.

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2.1 The emergence of a new ideology

Digital design thinking is more than simply a set of formal preferences. It is the *abandonment of the modernist design ontology* that is predicated upon formal and typological knowledge (e.g. formal languages, typological classes and generic design, etc.) It is non-typological and non-deterministic in supporting and preferring the differentiated over the discrete and the typological. There is emerging a *new symbiosis* between the digital product of design and the way it is conceived, generated and produced in digital media. These stages are fundamentally different from those of modernist design. It is the understanding and formulation of this procedural symbiotic relationship between conception, generation, production and the product itself that appears to be of high priority today. Digital technologies appear to have *freed the image from traditional concepts of representation*. We no longer represent discrete shapes in the conventional paper-based sense. This condition has enhanced the denial of classical notions of representational conventions such as static space, and has introduced new concepts of dynamic and responsive space and form that are producing new classes of designs.

In many cases approaches to form generation exploit *emergence-based transformational processes* in which digital media are the enabling environment. This in many ways is *replacing the experimental visual nature of the paper-based sketching process*. Context in the modernist sense may possess iconic, stylistic, or configurative content that can implicate design through visual or formal content. Context in digital design is considered a *performative shaping force* acting upon shape and form.

2.2 Paradigmatic classes of digital design models

These indications of conceptual change have emerged the formulation of design models, the conceptual content and vocabulary of digital design. A formulation through the identification of relevant early models of design has been developed by the author (Oxman [15]). The classification of paradigmatic models includes: CAD models, formation models, generative models, performance models and integrated compound models. This classification enables the definition of underlying current digital design models.

2.2.1 CAD

Early CAD models marked an attempt to depart from paper-based media. They had little qualitative effect on design in comparison to conventional paper-based models. In traditional CAD the interaction with formal representations supports the *a posteriori* automation of design drawings and visual models. First CAD systems were mainly descriptive, employing various geometrical modeling / rendering software.

2.2.2 Formation

In digital design the centrality of traditional concepts of paper-based representation are no longer valid conceptions for explicating the thinking and processes associated with digital design. Furthermore, in certain formation processes of digital design the formal implications of the concept of representation are negative and unproductive. Emerging design theory has transformed the concept of form into the concept of formation associated with topological, parametric and animation. Topological design is based on the exploitation of topology and non-Euclidean geometry. Parametric design is based on principles of parametric design (Burry [1]). And generative components, Animation, morphing (Lynn [12]) and other range of motion and time-based modeling techniques are based on the propagation of multiple discrete instantiations in a dynamic continuum.

2.2.3 Generation

Generative models of digital design are characterized by the provision of computational mechanisms for formalized generation processes. Here, as compared to formation models, shapes and forms are considered to be a result of pre-formulated generative processes. Currently there is a rich theoretical body of research-related applications of generative models. Two main distinct current sub-approaches are shape grammars (Stiny [18]; Knight and Stiny [7]) and evolutionary models (Frazer [4]).

2.2.4 Performance

Performance-based models are driven by performance and potentially integrated with formation and generative processes. Forces in a given context are fundamental to form-making in digital design. External forces may be considered as environmental forces including structural loads, acoustics, transportation, site, program etc. Information itself is also considered as an external "force" that can manipulate the design.

3 The conceptual content of digital design

We have attempted to build educational content by explicating the new conceptual structure of digital design. In reality, the integration and interaction of technological content with that of conceptual content is obviously part of the formative process of learning to design with media. However, the exploitation and experimentation with new concepts can prove to be an articulate environment for design learning (Oxman [19]) in which learning by making is transfigured by its conceptual, rather than computational, content. Given that a rigorous formulation of such emerging concepts does not yet exist, any work based upon an as yet unformulated body of theory must by necessity be in itself experimental.

3.1 Beyond formal representational design

The first stage of such a conceptual mapping is predicated upon the prevailing models of design at the level of their own conceptual structures. The prevailing model of modernist design is a formalist model in the profound sense of what we might term design ontology. Modernist design is formulated about the sequential development of symbolic representations of the design. It traditionally begins with considerations of space, with the major emphasis being upon the manipulation of visualizations of the design object –the design of form – through the stages of conceptual design, schematics, design development and materialization. The formal foundations of modern art and design have been theoretically defined and the evolutionary process of formal-graphical evolution in design representation has been well-formulated by various theoreticians.

We are now moving beyond this formal syndrome. The parametric, topological, geometric and generative characteristics of current digital design (Lynn [12]) are in profound theoretical contradiction to shape production in the formalist models. Irrespective of how unique that shape may be, it is still the process of shape production as the production of a static form. Digital design characterized by generative processes related to movement and time is neither formalistic nor static. Form generation, beyond formalism, produces conditions of pliancy and continuity in both the conception and geometry of form.

3.2 Formation, generation and performance: implications of the models

Formation, generation and performance are the motivating forces in the new design. They, as concepts and processes, begin to condition new design procedures that are uniquely conceptual. To some extent, these conceptual stages - in the establishment of an appropriate morphology for the design- are also non-contextual. Shreds, Strands, Bleps, Flowers and Folds are among Lynn's [12] interpretations of the morphologies of digital form.

First material, then generative procedure, and then performance appear to be the methodological sequence of digital design. It is this methodological sequence of procedures that supports the preference for time-related transformational states in place of the representation of static design representations.

This characterization of the digital design model is completely contradictory to models of design such as Schön's "reflective practitioner" in which the visual representation of the design is manipulated by visual reasoning through a succession of stages generally in the medium of sketching. This interpretation of sketching as design thinking through iterative stages of visual discovery is the antithesis of the digital model. Digital design brings new design ontology beyond the visual interpretation of form.

3.3 Digital systems as the medium for design process

The term digital design system, according to our definition implies the digital integration of attributes related to the morphology + structure + behavior of certain morphological-geometric classes of material form. Furthermore, in the studio the need for the integration of both the digital model and the physical model were found to be extremely meaningful for the conceptualization of digital material. Since current descriptive geometrical modeling lacks material and structural logic, the physical model provides a complementary medium. The physical model is still very useful for feel and touch in exploring principles of form, morphology and structure. Physical studies can then be translated into digital models for transformation and versioning.

4 Re-thinking digital design

In the following section a didactic approach in guiding three different paradigmatic projects is presented and illustrated. Each project was developed by exploiting digital concepts and techniques that suited the theoretical and conceptual content of the project. Each conceptual basis presented the designer with a medium for the development of the material concept through its parametric and morphological evolution. In each of the following selected projects a conceptualization of digital material and a unique digital process appropriate to the material concept and to the type of media is presented. Our didactic process consists of the following four basic tasks: the first task is to conceptualize and test a generic type of digital material. The second task is to define a unique responsive strategy for modification. The third task is to select a generative model. The fourth task is to select a context that can best demonstrate the behavior and applicability of the design material in relation to task specifications. In the following sections we demonstrate and illustrate these didactic steps in a series of selected projects.

4.1 Topological design: "The Boundary Wall"

The first project is termed "topological boundary wall". The specific context is related to a design program dealing with site conditions, programmatic aspects and constraints which vary along the length of a boundary line. The design material in this project attempts to apply topological conditions that maintain the same relations along the boarder line. It accommodates the new complexity of a certain topology, departing from the more static and typologically deterministic logic and design methodologies of the previous generation (see figure 1). The changing requirements found along the boundary create a constantly changing condition of context and program along the otherwise continuous design of the boundary. Together, the performance-based technique and the definition of parameters produce differentiation and heterogeneity in the design rather than the instantiation of a particular style, or standardized, modular structure as is currently routinely applied irrespective of complex changes of program and conditions.

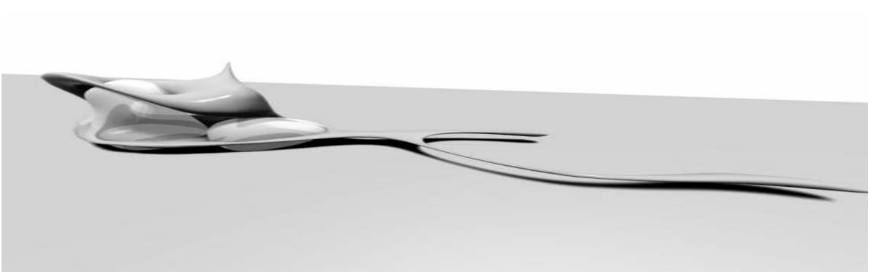

Figure 1: Topological design "The Dynamic Boundary" (designed by Farah Farah).

4.2 Parametric design "The Inner Space"

The next project is termed a "parametric Inner Space". The digital material is defined as a structural and morphological system of parametric and responsive modules (see figure 2). The design process resulted in the production of parametric differentiation of the continuous material morphology responsive to light. Light conditions were selected as a context to test the applicability of this system. Different interpretations of small and large scale applications of the material systems were integrated as local and global scale of particularization. The context of the lighting demonstrated the applicability of this parametric approach to specific light conditions.

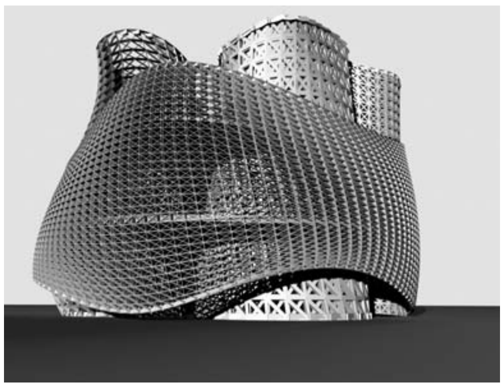

Figure 2: Parametric design (designed by Shoham Ben-Ari).

4.3 Generative design: "The 'texlight' mechanism"

The third project was termed "texlight mechanism". The conceptualization of the digital material is based on morphological principles of woven textiles. This woven material created an indeterminate range of heterogeneous folded profiles that were versions of folding and weaving principles. These profiles evolved to enable spatial, structural and environmental envelope functions within the woven matrix (see figure 3). The design transformations are defined by a set of syntactic rules (see figure 4). A Marina along the sea shore was selected as a context to inform the development of a continuously evolving structure.

5 Summary and conclusions

Our research has demonstrated that a new world view develops conceptual structures for design that may contradict the prevailing logic of design thinking. Rather than the employment of digital technologies, it is these emerging conceptual structures that strongly influence the logic of architecture and its design methods. These conceptual changes become the content of new pedagogical methods of design education. The awareness of change and conflicts can stimulate the necessary theorization and conceptualization for new approaches to design didactics. The "shock of the new" is not simply in the discovery of new formal vocabularies, but in the establishment of new approaches to design media. Among these, the election of the digital material as a suitable material morphology for a particular class of form generation has proved to be a productive and generative medium. Design thinking precedes design learning. The evolution of design thinking in the last decade now appears to have generated a new paradigm for design. As this paradigm crystallizes we first encounter it as a filed of conceptual conflicts between the prevailing and the new values of two design ontologies. New pedagogies can operate within this condition of the evolution and instability of ontologies. However, it can do so only by directly articulating and working with conceptual structures as pedagogical material. It is in this endeavor that we have established our studio for experimental didactics.

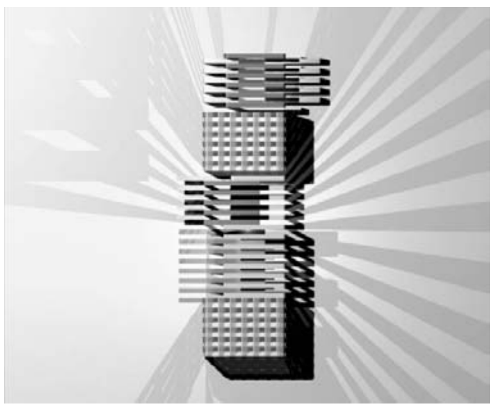

Figure 3: "Texlight mechanism" (designed by Alex Eitan and Tal Kasten).

Figure 4: Generative-set (designed by Alex Eitan and Tal Kasten).

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Construction of an electronic place by students and what they might be learning

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Abstract

Nonsense building is, I believe, what we are all engaged in, with and by. I am using the word nonsense to indicate two meanings of what might be being learned. The first is in the Victorian nonsense writing of not completely understood sentences and the second to mean that it doesn't make sense to me. This is an argument from the subjective point of view. It looks at the computing work done by a group of mid education students in the Architecture School, University of Auckland, in New Zealand. The intuitive learning of an architect is one of the reasons the education takes five years. We keep them going over and over things till they get an automatic response they can't identify as having been thought about. They come to a place they just know about and they (fingers crossed) are articulate about it. This contextual value of about right will be analysed as the place of discovery of the unknown elements of Architecture. The computer is enabling students to visualise but also it starts them to see the way in which the information contained in the database of the 3D model leads to other ways of using, and translating the information. These ways include shifting the information to another machine and its language.

The work also covers finding out what is available in our kiwi culture to build, create and generate Architecture. Sight, sound, colour and the on going bi-lingual exchanges between the work of shadows, drawings and the work of light, computing are programming the students of Architecture. The unseen defaults, the greys of gloominess, and the brilliant response and reaction of the high contrast values or broad tonal values, are all influencing the aesthetics, as a sensual perception, of current architectural practise.
Keywords: computing, thinking, designing, environmental stimulation, talking.

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1 Introduction

The work done for the paper ARCHDRC308 was offered for the first time this year (2006). The paper came at the start of the third year for most of the Architecture students. It was the first five weeks of ten weeks of delivered lectures. Five about computing and five about drawing, but the paper sits for these students in a line of papers that started with a set of twelve lectures in computing and twelve in drawing, for two years, so a total of forty-eight hours of lectures over two years. It was an opportunity to try something different as this group has done more computing than we will have again.

What I decided to try to do was get the students to see the board use of the computer in the construction of the Architecture they are interested in. It was a time for them to break out of the internalised world of the computer and get them to see the large number of small interfaces in the dynamic world of Architecture computing.

The work requested was getting them to step into talking and emailing people who are the culture, the people of the construction industry of Auckland and the world.

What happened was interesting as the different ways of thinking that were shown in the different approaches. Each group was either two or three people, but no two results were the same. The work generated was a flash file or a PowerPoint presentation that the students showed first to the class and then after a commentary they handed in the finished product that had to contain a number of things including a construction timetable and a costing of the pieces required to make the installation into the building.

1.1 Trial and error

But let's go back to my abstract. In the last paragraph I wrote;

Sight, sound, colour and the on going bi-lingual exchanges between the work of shadows, drawings and the work of light, computing are programming the students of Architecture. The unseen defaults, the greys of gloominess, and the brilliant response and reaction of the high contrast values or broad tonal values, are all influencing the aesthetics, as a sensual perception, of current architectural practise.

And I want to acknowledge research into the early child hood development, into learning, into the blending of cultures, into the work done, for caring into the work helping change peoples, lives into pattern recognition, into observation and start saying to you that the value of good is tied into the mediation of my body at a chemical , biological, and behavioural level. (I always worry that I am not yet seeing the complete me or them and that I might miss something, but that is always the condition.)

So Trial and Error. I choose this because it is part of the mechanisms of evolution. In a time where the possibility is that we are not evolving as we have in the past perhaps because we have, must have, mediated our environment in some very distant past. I think of getting out of the wind as an indicator of a process of evolution that is trying to achieve comfort but I think of wrapping up warm as a result of human mediation of the environment to achieve comfort, but those lines are something to be developed else where. Here I want to think of the mediated environment as being the place of exchange between educator, student and computer as well as the situation in which they sit, or stand.

So I think of trail and error and chuckle about the fact that the belief structures being generated around the computer in artistic and scientific endeavours are that if you make a mistake, it won't work. If we think about it we know (and therefore don't know) that it is our mistakes, it is our assumptions followed by things that disprove our assumptions that trigger us into changing our behaviours that trigger us into developing a new method of contending.

We fix the error by trailing new methods. We handle the situation by trying and learning. We eventually learn, are programmed by our choices. So the programming is triggered by our environment, internal or external, and we, not some raving lunatic, are choosing our programme, although the testosterone levels do play a part in the education of most architects.

2 The methodological approach

Nonsense building is, I believe, what we are all engaged in, with and by. I am using the word nonsense to indicate two meaning of what might be being learned. One as in the Victorian nonsense writing of not completely being understood, or in this case not completely understanding meanings, held by the student after engaging with the activity we have given them. Here in this work we end up with narratives, poems and lines of thinking that getting us thinking. If we look for ideal or 'correct' answers, we will find frustration in ourselves, but in the students we will see thinking shown in a couple of ways.

First: "the let's throw this together as fast as we can because life has been great and I don't care about this assignment." A valid response and one which we need to accept and provide a default answer. The answer that we show them. In this particular case it also ended up being one of the best. This answer being shown is interesting because often in Auckland New Zealand in my teaching they choose to rebel much in the way students don't read the books you recommend or resist until the last moment, often it is done in a really simple way with not much thought is given by the student to the assignment.

Second: the "Cool the computer can do anything and so can I, so, let's try to do everything." This can produce very good results but is fraught with problems when people don't quiet get there, when pieces are missing because the story, the line of thinking is yet to be completed.

Third: the "Tell me what to do and I'll do it." This is the most dangerous of all for creativity and therefore for the generation of "star" architects. It is still valid but it is part of the group, part of community generated Architecture… (and again here is a line of thinking for another time.)

Fourth: the "I will just do what you say because you know and I don't." this is the one that frustrates me most and it is because just like just, it indicates a devaluing of the work by the student and more problematically it indicates a shutting down of the thinking about the issue, in favour of someone else's thinking. And yet I know this to be an important part of the multiple centred design approach learning not to hold on to tightly to something which is not important, really… (and again here is a line of thinking for another time.)

And I am sure I could find many more. I recognise many blends much like wine or scotch. You can blend and mix 50% this 45% that, and the final 5 might be the washing of a strange barrel or the gem of a moment.

Two: in the it doesn't make sense to me. A colleague told me after forty you can't talk to students, they just don't "get" you. Charles Walker eminent academic and architect suggested that we move with our friends into a position of old people. Really very useful in some ways and entirely problematic in other ways, useful because for some students they will believe you because you have been here long enough and problematic because the others will just say what do you know and the answer they will find for themselves. The hope is that in all that work somehow we manage to get something to stick, if not in the conscious mind at least as a pattern in the subconscious mind. And the metaphor here is the lolly scramble. We throw things up into the air, and with some luck, we then are able to watch a few people get the lollies and savour the sweetness. We are able to then watch the frustrated circle around say that they didn't want it anyway. Those beyond that have the "ah I didn't try for it" and those who seem further away are engaged, watching and observing. The observation sits and may be committed with the assistance of mirror neurons to memory or not. Brainwashing and education of the architect, of any profession, are all similar. Both seem to wish for us to put our health at risk, to not sleep enough to eat badly to abuse ourselves in ways we wouldn't allow others to or we would insist on in the 'if I did it this way you will do it the same way'.

This is an argument from the subjective point of view. The identification of the types of subjective points of view are caught in a behaviourist issue of how do I know, of how do I find out, when I know of the flaws in perception and interpretation.

In a methodology, it is necessary to work out a likely response, which I did and was of course wrong. Again, the nonsense of research and learning is what we are dealing with. Remember I am using the word nonsense to indicate the level of learning/understanding that the participants had before the project was started.

The students and I had three lectures to look at the work done in Kolarevic, B. and Malkawi, A. (2004) *Performative architecture : beyond instrumentality,* Spon Press, New York. To look at the New Modernists, Folds, Blobs and Boxes. The DVD is produced and directed by Michael Blackwood but the thinking is lead and directed by the interviewer Joseph Rosa. Diller and Scofidio in Aberrant Architectures. Another DVD and the third DVD is not it is a video with architects talking about Reimagining Manhattan after September 11.

I want to credit the thinking but it gets very difficult. In a book the author is the king pin but in the collaborative effort who do I credit..

The final result handed in for marking I understand even less. But in this the subjective point of view, I am looking for things, parameters and the interrelationship between the variables with in the project. A consideration of how do I tell. What do I tell. What is enough information, what is too much information. What I want them to do is to make a positive conscious choice, for me, so yes it is tailored to me. I don't want them to do exactly what I have done, it is not possible for them to as in six hours and the previous two years we haven't given them enough time to rote learn ways, what I believe we must do is show and model behaviours. And get them to draw and map enough ideas, concepts and lines to appropriate help. Some will get the sweet of the lolly scramble and some wont but they will react in the range of ways. I don't want it, I didn't try and I was just looking. But with a bit of luck they were there and they did see and they therefore did get something more than just a nap.

3 Theoretical approach

3.1 Two lines of thinking: my nonsense

3.1.1 About the learning

In learning we start with the situation of very broken fields of knowledge in both the educator and the student. Partial knowledge is used to find similar positions and then to start discussing the possible implications of that in the chosen field.

This is the same mechanism that generates culture. In learning we instruct and coax a student into believing what it is we believe. In most cases we are working from the knowledge and interpretations of others. We very rarely get to engage in knowledge formation. In a philosophical argument it is not possible even when we see or hear the actuality of the experimental result because always we are engaged in the act of interpretation. What our eyes or ears deliver is only understood because we are train in the interpretation necessary. The world was flat when judged by experience but when knowledge of travelling around it became commonplace the world was a sphere in space. Not until the abstract implications of the world not being the centre of the world were we able to understand the implications of planets, wanderers and therefore start building a knowledge of our solar system.

3.1.2 About culture

In culture we build as suggested by Bhabha's theory of cultural hybridity and attempt to understand connections that have not been seen in global and colonial ideas. This pattern of understanding and re-discussing is, I believe, with in the nature of culture, and as Architecture has come to understand the computer in Architecture. It has seen a cultivation of interesting change in the ascetics used in the field. It is also the pattern that creates the possible understandings of reactive or a need for haptic responses in Architecture.

Architects need to be are different when they leave schools, but one generation is always different to the next. The architecture industry is different as a global phenomenon and different as a local manifestation. The built form of Architecture is different. The dreamed version is different. In New Zealand, we train roughly 200 graduates a year who are headed near and far. When our

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students look for exciting culture it is not found in the buildings they see. Rather it is in the nightclubs and that is might well be "house" in a building. The experience of joy is in experimentation in social placement but it would seem not in building. The building is not generated by the testing and free form possibilities of a computer or digital world. The building culture in New Zealand is one of timber buildings with just a few metal-framed buildings and in most cases, most architects are dealing with housing, or the domestic. At this scale of the culture of New Zealand, it is shown in the house.

3.1.3 So that is about three (at least)

So what happens when we ask for a students to go and find ways of using the computer in the Architecture they are currently dreaming of. They come back with many ways of 'building in' an interactive moment. In most cases they find ways of building clever or smart but conventional floors or walls. In this mid-education exercise, they are still conventional or are already imbibed to our way of thinking in our, their culture.

Next time I do this paper it will require that the students cite an example that they site a building from previous example, that they look further away and I need to find and show images of boats, surf boards, and any 'other' building tradition. In New Zealand we are privileged to have many cultures. So we could point to the tukutuku weaving of walls from Maoridom, the paper wall traditions of Japan, or to the steel and concrete of the Hawkesbay, to the lighter traditions of buildings in the warmth of the north and the rapo and stone building possibilities in the south. Some how I must get across that we have a lot in New Zealand besides the DIY, building in timber and gib.

4 Changing conventions

4.1 Dreaming

So how do we change the conventions of a small country? I have dream, a dream of never seeing the grey architecture image. The image generated by default light in the environment. I know that I will in 20years be teaching the same things of perception and subtractive and additive colour but I hope in 20 years the students I am currently teaching won't be accepting default lighting of a CAD package as satisfactory. That we will be playing with the biggest difference the computer offers. The light of the computer rather than the shadow of the drawing. That maybe, just maybe, the students will start to see the drawing conventions are wonderful but when working with the computer they need to think about that medium of light. Anyway this is a digression, but it points to how over the next couple of decades I will be attempting to change the desires of students by showing them that the rest of the world is fully engaged in the digital worlds of new materials and new methodologies and really it is just the same old stuff of form, light and human perception that we use when designing. I will be doing no more or less than giving them the opportunity to take up the issues of their culture and work in ways that reflect and modify their culture.

4.2 What is new

Bhabha talks about how 'new' enters into our cultures. He types into the descriptions the notion that the blending of other and colonial or in our case that the blending of the draw and hand as being colonised by the digital production and screen, happens because "of the struggle of translation in the name of modernity? How do we catachrestically seize the genealogy of modernity and open it to the postcolonial translation? The 'value' of modernity is not located, a pirori, in the passive fact of an epochal event or idea – of progress, civility, the law – but has to be negotiated within the 'enunciative' present of the discourse". pg 242

So to interrupt this for students I would say Bhabha tells us to talk about things, cringing as I did so and hoping the geist is enough. That we need to speak draw or write and we now can add compute is not silly but does place the architecture in a place where it will be misjudged, misunderstood and it will misbehave. In this place of nonsense of partial knowledge, it will leave not new but retranslated and reinterpreted, new to us this time. This contextual values of about right, it sort of means, is the place of discovery of the unknown elements of Architecture in and of the "she'll be right culture".

"The new or the contemporary appear through the splitting of modernity as an event and enunciation, the epochal and the everyday. Modernity as a sign of the present emerges in that process of splitting, that lag, that gives the practise of everyday life its consistency as being contemporary. It is because the present has the value of a 'sign' that modernity is iterative; a continual questioning of the conditions of existence; making problematic its own discourse not simply as ideas 'but as the positions and status of the locus of social utterance." pg 242

So Social Utterances are important. In the crits we give, in the seminars we require, our architects are learning to coax cajole and teach us, now and then they will coax cajole and teach clients.

The students of Architecture need to know that their Architecture will sit and utter the positions the status the locus of culture, they are running at the moment and need to engage more with the histories and ideas and methods and in so doing reconstruct themselves.

"… the projective but ideal speech community that is rescued within modernity by Habermas in his concept of communicative reason that is expressed in its pragmatic logic or argument and a 'decentred' understanding of the world: what we encounter in all these accounts are the proposals for what is considered to be essential gesture of Western modernity , an ethics of self construction' …
I want to ask whether this synchronous constancy of reconstruction and reinvention of the subject does assume a cultural temporality that may not be universalist in its epistemological moment of judgement, but may, indeed, be ethnocentric in its construction of cultural 'difference'." pg 240

And to what ethnicity am I thinking, to one which is already tied and caught in the pluralistic understanding of Auckland's current student culture. I am pointing to a period that is not only physical aging but is exposure to ideas and is also innate curiosity and activity. That the ethos is the blend of the wine and is this gem or washing of the barrel, is this sweetness of the lolly or the watching of the game? And find myself restablishing requestioning in a construction of my own identity, ever caught in this debate of "who are you, so therefore I am?" That evolved sense of self-discovery, which is about position, about a reading of social utterances and a judgement and a valuing of worth. What ever we discover about the world is also about us. The 'you don't like' statement and the 'you like' statement are very important to the majority of our estrogen influenced students because they are environment readers and without the assurity or confidence of tesrtone the object obsession shifts in its focus.

The students who find themselves at the top of the grades in Architecture will I hope get a really bad, opps no dud(?) (trying to find the social and the least judgemental word.) so they are able to practise the 'let it go' when they get something not to their liking, be it bad or good, because we don't know what they think or want, in most cases.

And what does this have to do with the places of information delivery in/on a computer. Lots and absolutely nothing, except that in a learning institution the person who sits at the computer is what I, as an educator, have been watching and wondering how do we teach you. We don't they learn from the things they choose. What the motivation is for why they are doing what they are doing is only knowable by me because humans as individuals are never the same, but humans as individuated members of the collection start to group in statistical ways so the behaviours I see are possible but not assured. The only way of judging the individual is in some form of social utterance, paper, test, lecture, model, and or book, What the machine has made resource possible is the private learning and the private testing that the University believes. The computer machine is digital but is simply another form of information exchange. The web, the email, the TV, the digital are techniques not answers. The content in that utterance of a student is judged, is placed by both sides of the utterance exchange, whether the two sides are visible or not, whether they share the same values.

The computer is a poor subset of our lives, is a poor collection of information, but it is a great testing environment. It is not an object or tool for a lot of us. It is a 3D place and as the web seems to be returning to 2D delivery of information I hold on to the hope that we, particularly the architects, will "get" that the ability to think in 3D is what makes the difference.

5 The work itself

The sight, sound, colour and the on going bi-lingual exchanges between the work of shadows, drawings and the work of light, computing is immersing the students of Architecture in a world that satisfies the evolved needs of their perception system. It is this satisfaction that is problematic, good enough is not enough when it comes to a value laden judgemental laden thing like architecture. What we require of our students is the activity that is embedded within this argument.

We require that students work with “the present (which) has the value of a ‘sign’ that modernity is iterative; (it is) a continual questioning of the conditions of existence; making problematic its own discourse”

(So have they and do they? Please continue judging and valuing them yourselves as they appear and disappear.)

While you do that let me continue to carry on. The nonsense we see being built by students who are looking out into the building culture is interesting as it shows at least two things. One is the strange result of not seeing things that looked like the Architectural moments portrayed in the New Modernists folds blobs and boxes. Or in the text Performance Architecture. Beyond instrumentality edited by Branko Kolarevic and Ali M. Malkawi. And two the control freak stuff, raising itself in the chance to react with a building.

In most cases there was no meaning put up with the work. There was just the sense of fun that be had with the Architecture. And the child in me likes that it might simply be fun but the architect within is pretty sure that the moment that the architect is not telling but reacts will have layered across it many meanings by people who currently still hunt for the thing that the environment tells them.

It is not at the conscious level it may not be subconscious or preconscious but it is the same value and judgemental thing we evolved to decode the world we live in. The reading, cognitive, Freudian or otherwise I leave to others, it is just that what we see is that learning is lifelong, the development rearrangement is life long and the accumulation and discernment and refinement is life long. What I think I am now seeing is a shift to where our students will learn. Because as I typed in a email the other day it is not the mechanisms is not the feeling of the pencil it is not the feeling of the card it is not the flashing of the light it is not the movement of flight. It is the insight that students get and then it is the cleverness in which they deliver that to someone else.

The work also covers finding out what is available in our kiwi culture to build, create and generate Architecture. And I would have thought the boat building of the yatch mad city of sails would have meant the fibreglass or wooden ribs or the sails would have featured but they didn’t. It was however the technology of the interactive moment that was picked up. It was of the information handling that they were interested in, perhaps a modelling of themselves as they hunt for the information but I think it is a significant change rippling across our cultures, or may be they saw through me. This shift in interest is difficult. It is difficult because in Architecture we have used the mechanistic as a simple technology based way of giving value to Architecture. Is this interactive reactive moment in Architecture simply a ‘new’ problematic value? Architecture in its own time scale of 25, 30, 50 or 100 years allows us to think slowly. The computer allows us to communicate quickly, sometimes.

What has been interesting is the shifting of information to another machine and those languages to the small digital conversational like programmes of control. Most popular would have been the switching generated by picking up information and the reaction or response of a control programme as shown by the interactive wall or ceiling.

As a maker I work nights because it allows me to suspend my thinking and trust my creativity, those accidental triggers flowing in the brain.(think solenoid or induced flow in wires) As a writer I write when my brain is fresh and so able to analyse, after sleep, in the morning when with concentration it is possible to stop listening and write what it is. But behaviour changes and life intervenes so sometimes we just have to do what we have to do, change our minds therefore change our behaviour which others can then mis-interrupt as they see fit, or should that be to fit.

The argument can only be subjective until it is shared when it might become objective.

The construction of an electronic place by students and what they might be learning can not be known can only be misjudged unless they choose to engage in the social utterance.

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