Lutz Walter
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Editors

Transforming Clothing Production into a Demand-Driven, Knowledge-Based, High-Tech Industry

The Leapfrog Paradigm

Springer

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Springer

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Preface

In 2001 at EURATEX's office in Brussels, the sight of two divergent lines on the same graph gave birth to LEAPFROG. The first line showed a surplus in the then EU-15s balance of trade in textiles (yarns and fabrics) that over the years had grown, albeit slowly. The second line showed a rapidly worsening trade deficit in apparel. This was at a time when the textiles and apparel industry as a whole was conscious of the massive additional pressures it would face when China joined the World Trade Organization and the quota system that had governed international trade in textiles and apparel for close to forty years disappeared in December 2004.

The conclusion drawn from the two lines on the graph was simple enough: high-wage countries cannot compete with their low-wage competitors in labour-intensive industries such as garment manufacturing, whereas a high degree of automation, as was the case in the spinning and weaving industries, does enable industries to remain competitive and export-oriented, provided that international trade is free and fair.

Hence, the idea of automating apparel manufacture with the triple objective of: eliminating the wage handicap faced by the EU apparel industry, bringing apparel production back to Europe, and achieving a fault-free production process. A successful outcome would also, importantly, provide jobs in the EU that would be better skilled, more stable and better paid. It would, in addition, provide more opportunities for EU textile manufacturers whose fabrics would, in all logic, be the raw material of choice for the LEAPFROG manufacturing process.

At that point, it is doubtful whether the group looking at the graph had any clear concept of the lines along which research and development would need to proceed if success was to be achieved. They certainly did not have any 'James Watt moment' enabling them to see how a specific phenomenon could be harnessed to automating garment assembly. It is even more doubtful whether they even gave thought to the essential mechanised preparatory processes required to ensure that pieces of fabric reached the precise location for the chosen joining technique to occur. But they did have the vision to appreciate the step change that their concept would provide and the advantages that European industry itself would derive from it. On this basis it was a relatively easy task to spread the word and to inject similar levels of enthusiasm into some of the best brains in the European scientific community and into highly successful and forward-looking manufacturers within the European Union.

As a result of this growing enthusiasm and the recognition that LEAPFROG has acquired as a flagship project for the EU apparel industry and its textile suppliers, there is little doubt that the industry image has also been enhanced, and its credibility with decision makers at Government and European Commission level has undoubtedly also improved.

The present publication describes in considerable detail the work that has been undertaken to make LEAPFROG a technical reality. It also addresses quite soberly the difficulties encountered over the four years' duration of the project, and the challenges to be overcome if LEAPFROG is to be commercial reality. Above all, today, however, it is the belief of European manufacturers and investors that will determine in the final analysis whether LEAPFROG is to play its full role as the saviour of the EU garment industry, whether its findings are exploited beyond Europe's boundaries, or allowed to collect the dust on forgotten library shelves.

Brussels, Belgium, April 2009 *William H. Lakin*

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An array of people deserve and have my great appreciation for making this book possible. There are first and foremost my two coeditors George Kartsounis and Stefano Carosio. George was the planner and organiser who set up and implemented the whole project of gathering the various inputs from all contributing authors. With a tireless dedication to all the necessary details from the first planning stages up to the delivery of the final manuscript he was the driving force that kept us all on track. He also made contributions to the introductory and concluding chapters and provided valuable support in reviewing chapters two and three. In addition he authored two sections.

Stefano, together with his colleague Tanya Scalia, who did an excellent job during a far from easy period, deserve credit for their invaluable support in ensuring that each and every contribution meticulously met the overall structuring and formatting requirements.

To effectively handle the complexity of the research work in the described LEAPFROG project, it was from its start divided into four research modules, which are also reflected in the four main chapters of this book. The four research module leaders, Rezia Molfino for Chap. 2, Stefano Carosio, supported by Tanya Scalia for Chap. 3, Eric Boudon supported by George Kartsounis for Chap. 4 and Thomas Fischer supported by Dieter Stellmach for Chap. 5, each made sure that truly representative sections of high quality for all research modules were selected and delivered in a coherent and overall integrated way. In addition Thomas Fischer and Dieter Stellmach provided valuable input to the conclusion chapter.

Among my colleagues at Euratex there is of course Bill Lakin who can be rightly called the founding father of the LEAPFROG initiative. Bill fully believed in and relentlessly supported this project since its very beginnings back in 2001. Then there is Mauro Scalia who bears the brunt of the daily management and coordination of the more than 40 partner organisations and other contributors and the almost endless number of tasks and related delivery deadlines that constitute the LEAPFROG project. He directly contributed to the introductory chapter. Francesco Marchi, who as no one else knows the economic structure and

dynamics of the textile and clothing industry in Europe and beyond, helped me with the provision and correct integration of the key industrial and trade data in the book's introduction.

Finally, I would like to thank John Cleuren of the European Commission, LEAPFROG's project officer, who has proved to be so much more than just a controller of the actual fulfilment of the contractual obligations by the project consortium and who through frank and knowledgeable advice helped overcoming the occasional difficulties and set-backs that the complexity and high-risk nature of such a project inevitably bring along. I would like to say a final and special thank you to John's former colleague Odile Demuth, who was an enormous supporter during the project's preparatory stages. All who know her today and had the pleasure of working with her in the past miss the fascination and dedication she would have undoubtedly brought also to the implementation of this project.

For me it was and is a great privilege and pleasure to work with all the aforementioned people as well as all other authors of this book and all the unnamed further LEAPFROG partners. It has been an enormously enriching experience to work for this flagship project of an industrial sector, which is too often wrongfully characterised as too traditional and mature for great innovation and I sincerely hope this books further helps to dispel this myth.

Brussels, Belgium, April 2009 *Lutz Walter*

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Chapter 1
Introduction

1.1 The European Textile and Clothing Industry in the Global Environment – Reality and Challenges

Lutz Walter, Mauro Scalia, Francesco Marchi

Industrial manufacturing of clothing has over the last two decades become a truly globalised operation enabled by dramatic changes in the global political and economic context in which this industry operates.

On the economic side significant changes with impact on clothing-production patterns have occurred both in the industrialised and the developing world. Industrialised countries have witnessed significant changes in the structure of the retail distribution of clothing to the end consumer generally moving towards an increasing concentration of market share in the hands of larger national or international retail chains. In Europe, these trends are most pronounced in Northern and Western Europe where the remaining share of independent stores has dropped mostly below 20% sometimes into single digits. In recent years also Eastern Europe has seen an accelerated trend into that direction (Baker, 2007).

Apart from the more traditional department store and specialised clothing chains general retailers such as Wal-Mart, Carrefour or Tesco as well as hard discount retailers have also become major forces in clothing retail, leading to a concentration of purchasing power on the distribution side of the business and enabling access to remote low-cost manufacturing locations thanks to the sophisticated global sourcing, transport and logistics operations that these large companies can access or themselves orchestrate. Such concentration trends in the distribution sector have not been matched by a similar consolidation on the manufacturing side that remains highly fragmented and dominated by small to at best medium size companies. In the European Union, the average clothing company has 19 employees, the average textile-producing company 25 employees. This stark imbalance of market power between the retail and manufacturing sectors has led to a situation where the distribution side very much sets the ‘rule of the game’ and reaps an unproportionally larger share of the economic value generated in the supply chain (Baker, 2007).

Developing and emerging countries on the other hand became clothing manufacturing locations of choice as their economic and financial systems improved, their industrial and logistic infrastructure was developed rapidly and a massive migration of rural work force to the industrialising cities and development zones provided an abundance of cheap manual labour for a manufacturing system that does not required very high levels of skill and knowledge from its production workers. In some emerging countries like China, India, Pakistan or Turkey the expanding clothing manufacturing sector also increasingly benefits from abundant local supplies of textiles thanks to the build-up or massive expansion of textile-production capacity from fibre – mostly cotton and man-made fibres such as polyester – often led by government-owned companies or private companies benefiting from privileged access to public funding.

Globally sourcing retailers and wholesalers massively exploited this opportunity for significant reduction of their purchasing prices to the detriment of textile and clothing manufacturers in industrialised countries which due to their higher input costs (labour, capital, energy, environmental and consumer-protection compliance, etc.) were increasingly unable to match prices offered by developing country producers. This led to constantly shrinking margins, thousands of company closures and contributed significantly to the job losses that occurred over the last two decades (Institut Français de la Mode, 2007). Despite this, the EU textile and clothing industry in 2007 still employed 2.5 million people across some 160,000 companies generating a combined annual turnover in excess of 210 billion Euros. In order to stay competitive companies have been undergoing continuous restructuring and modernisation processes (EMCC, 2008). As part of these processes they often invested heavily in new technology, research, product development and innovation capacities, adopted new business concepts and entered new higher added-value markets, resulting in continuous and recently accelerating productivity growth (Euratex, 2006; see also Fig. 1.1).

Thanks to this, the European Union today still occupies the position as the world’s second biggest exporter of textiles and the third biggest exporter of clothing. While the enlarged European Union over the last ten years has barely held on to its global position in textile trade, the United States and Japan have significantly declined, whereas emerging countries led by China have taken a large and still growing share of the global textile and clothing market.

The changes in the global political and economic contexts have been truly transformational. The same cannot be said across the board for the third crucial dimension of an industrial sector’s development – manufacturing technology. Textile production, technologies for core processes such as spinning, weaving, knitting, dyeing, printing and finishing have indeed seen significant developments enabling massive productivity gains over the last decades. The same, however, does not hold true for clothing manufacture where the technological centrepiece of production – the sewing machine – has not witnessed any revolutionary changes since its intervention in the mid of the 19th century. The large productivity gap

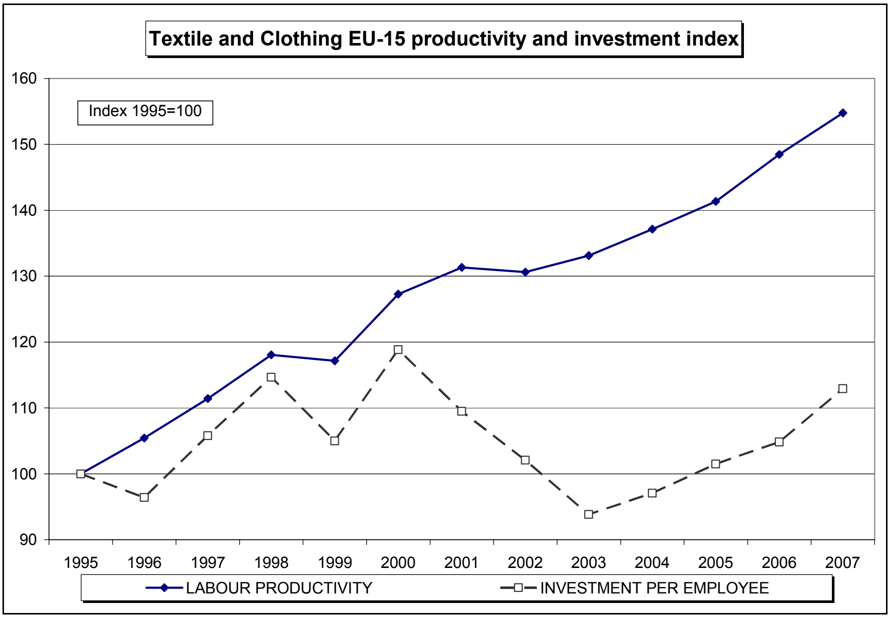

Fig. 1.1 EU textile and clothing industry apparent labour productivity and investment indexes, source: Euratex

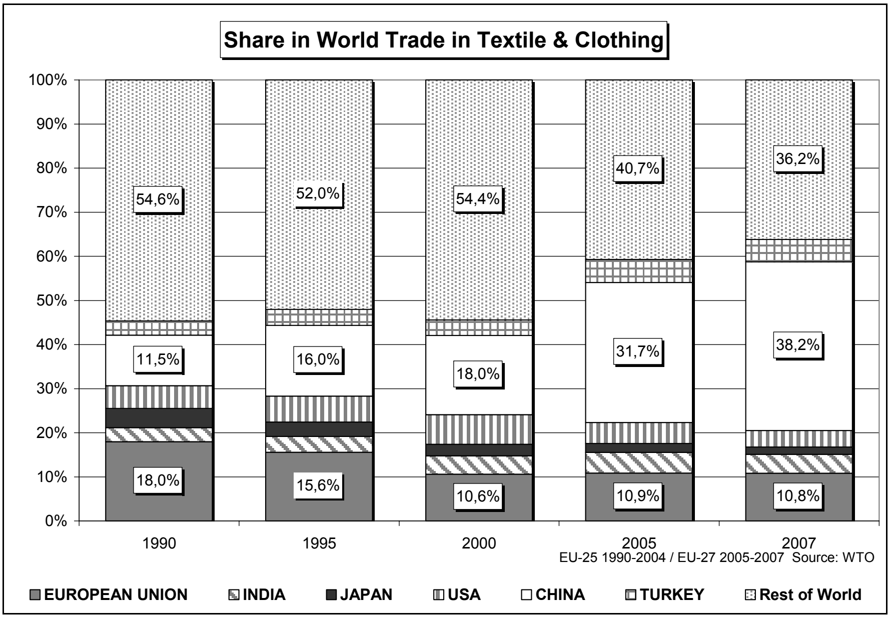

Fig. 1.2 Development of shares of global trade in textiles and clothing (excluding intra-EU trade), source WTO data

between the textile and the clothing sector of a magnitude of approximately 2 to 1 is probably the most striking witness of this situation.

It is true that a number of semi- or fully automated technologies have been introduced on the garment manufacturing shop floor such as spreading, nesting, marker making and cutting system and to a certain degree in the ironing and garment finishing processes (OECD, 2004). Despite this, major parts of handling and joining operations remain highly manual labour intensive making the whole garment making process uncompetitive in high labour cost countries.

The industry's response of a major shift of manufacturing to low labour cost countries often far away from the point of sale/consumption of the final product has in turn introduced additional complexities, risks and costs. Long lead times, challenging logistics and quality assurance procedures, a lowly skilled work force as well as a higher vulnerability to IPR infringements plague these operations sometimes coupled with political or social instability or higher economic and financial volatility in these offshore manufacturing countries. The related costs and risks are borne by manufacturers and distributors alike and also limit them in the adoption of new business models based on:

- ultra-fast response to end market changes;
- deeply consumer involved industrial scale customisation and personalisation of products;
- smart flexible networking in open value chains and business communities;
- use of the latest b2b and b2c e-business technologies.

Such new business models have, in a number of significant individual cases, proven their potential for significant economic value creation in an end market that becomes more and more segmented, fragmented and fast moving. However, for a majority of industry players locked into the 20th-century paradigm of labour-intensive mass production at low labour cost locations using 19th-century manufacturing technology concepts, such value creation remains an elusive potential.

The LEAPFROG project set out to prove that the necessary concepts and technologies for a radical transformation of the clothing industry are largely available today or will be in the very near future so that it is up to visionary entrepreneurs and business managers to make use of them to create the textile and apparel industry of the 21st century.

1.2 Rationale and Technological Approach of the European Integrated Research Project LEAPFROG

Lutz Walter, Mauro Scalia

LEAPFROG, the biggest ever EU-funded research project in the clothing industry, attempts to overcome the above-described predominant paradigm of mass production of clothing at low labour-cost locations and demonstrate that the textile and clothing manufacturing sector can be transformed into a demand-driven, knowledge-based, high-tech industry by exploitation of recent advances in a broad area of scientific-technological fields, notably

- nanotechnology and advanced material science;
- robotics and innovative textile joining techniques;
- 3D computer graphics and animation;
- information and communication technologies for e-business;
- organisation science and management research.

The initial project idea was conceived by Euratex in 2001 and after an intensive preparation, expert networking and consortium building process a proposal for an Integrated Project under the Nanotechnologies, Materials and Production Programme (NMP) of the European Commission's 6th Research Framework Programme was submitted in early 2004. After successful evaluation and contract negotiations, the project with an initial consortium of 35 partner organisations from 11 countries under the leadership of Euratex started in May 2005. The project has a duration of 52 months finishing in July 2009. The total project budget approached Euro 25 million of which the total EU funding was close to Euro 14 million.

At the start of the project the Association for Advancement and Dissemination of LEAPFROG Technology AADLT was founded to enable a larger group of interested European textile and clothing companies to follow project progress closely without necessarily becoming involved in technical development work, but with the objective of joining demonstration and training activities organised in the later part of the project.

The following sections divided into four chapters reflecting the four major research modules of the LEAPFROG project will describe the main research and development tasks carried out during the project as well as their final or preliminary results.

Chapter 2 contains five sections that describe the project's research and development work in the field of automation of the major handling and joining, i.e. sewing, operations, which at today's state-of-the-art garment manufacturing sites are almost exclusive manual labour tasks. The key innovative concepts behind the accomplished technical developments are:

- a fully automated pick up of (single-ply) cut parts from the cutting table based on a novel highly reliable non-damaging grasping system and an automatic transfer of the flat hanging cut parts into a conveyor system;
- the placement and fixation of the cut parts onto a size-adjustable 3D mould;
- the sewing operation by means of a freely 3D movable robot-guided sewing machine and an automatic acquisition of the correct robotic sewing path from CAD data of the garment to be assembled;
- the integration of all those innovative components together with state-of-the-art technology into a holistic automatic garment assembly line complete with necessary machine–machine and human–machine interactions.

Chapter 3 contains three sections that describe the project's research and development work in the field of innovative materials and related processes. The key innovative concepts behind the accomplished technical developments are:

- The concept of using shape-memory polymers for the production of textile-grade fibers and filaments, for the sake of facilitating assembly automation. Shape-memory polymers (SMPs) are featured by their capability to change shapes in response to external stimuli and have recently been proposed for textile applications. Results derived from LEAPFROG development work on shape-memory polyurethane polymers and their fibers for textile applications, are described.
- The application of new laser-bonding methods to enable greater flexibility in the design of garments and a higher degree of automation. The results of feasibility studies are described, followed by a description of the preliminary equipment that is now being prepared and the results of more detailed studies for textile and process definition.
- The use of permanent and temporary stiffening agents. Permanent stiffening agents have been used in order to reduce the complexity and the number of parts to be sewn together required in particular for the interlinings that have to maintain a pre-defined shape (plastron, shoulders …), while temporary stiffening agents have been tested with the aim of facilitating automated material handling and sewing, including physical removal after garment integration.

Chapter 4 contains four sections describing some of the key results related to the critical first steps of new product development (NPD), namely the design and evaluation of a new collection in terms of virtual, instead of physical prototypes in a collaborative manner. Design and prototyping are critical activities in order to meet consumers demand for ever expanding variety of new collections. The key innovative concepts behind the accomplished technical developments in this area are:

- A methodology for body-shape analysis based on hierarchical statistical clustering in order to derive representative female and male morphotypes from sample data obtained during an Anthropometric Survey with the use of whole three-dimensional (3D) body scanners.
- A comprehensive methodology for garment design effected directly in 3D, to be used throughout the process of product design and product development. No physical prototypes will be necessary for this process as they will be replaced by virtual prototypes. The aim is to offer a new approach to reduce the time-consuming tasks of design and prototyping currently based on 2D CAD systems and physical samples.
- The integration of all research results related to the NPD process in the form of a web platform enabling e-collaboration between potential users of 3D design and Virtual Prototyping, such as product managers, designers, modelists and sales and marketing personnel in a scenario intended to speed up and enhance creativity and effectiveness. The CVP is linked to other satellite web-delivered services, such as a fabrics library, a cost estimation module and a real-time animation module, offering visualisation of animated virtual mannequins 'dressed' with the new creations.

- A new simple, fast and very low-cost method for the approximate estimation of key fabric parameters required for the simulation of fabrics, by employing automatic image analysis of the projections of illuminated circular fabric samples.

Chapter 5 contains five sections describing results of development and industrial demonstration of concepts, methodologies and technologies related to the three dimensions of networking – organisational, knowledge and ICT networking – of a smart organisation doing business in the textile and clothing industry. Such an extensively networking company, defined in the LEAPFROG project as an extended smart garment organisation (xSGO) would use and benefit from:

- smart network modelling as a tool for analysing, designing and coordinating its relationships with its networking partners;
- the implementation of a new quality partnership along the textile-clothing value chain based on harmonised highly knowledge-based quality assurance processes for faster, more efficient and reliable collaborative product development and production ramp-up processes;
- the development of a coherent knowledge exchange infrastructure based on ICT interoperability and a seamless information flow to enable fast, efficient and reliable set up of open textile and clothing business communities;
- the application of product tracking and tracing technologies including RFID and the integration of derived complex data into a new generation of supply chain event management systems.

The presented sections summarise the collective research and development work of virtually all the scientific and technology development partners involved in the LEAPFROG project. Wherever available and appropriate the research results description is supplemented with findings from testing and demonstration work by the project's industrial partners in real pilot or full-scale business environments.

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Chapter 2
Automated Garment Assembly and Manufacturing Simulation

2.1 Robotic 3D Garment Assembly and Automatic Material Handling. Is it Feasible?

Philipp Moll, Ulla Schütte, Kerstin Zöll

Abstract Presently, garment production is extremely personnel dependent and therefore cost intensive. Robotic 3D assembly offers very interesting possibilities and potentials for high-tech and high-quality garment manufacturing with improved quality, cost reduction and fast response to consumer market. The special robotic 3-dimensional (3D) sewing technology, researched and developed by Philipp Moll GmbH & Co, makes it possible for the first time to sew 3D seams automatically. Textile cut parts are placed onto the 3D mould. The special sewing machine is guided by an industrial robot along the spatial seam course similar to welding robots in automobile production. One important aim was the development of an adjustable mould, which can adapt to different sizes and shapes of garments. The concept of the adjustable mould for jackets is a special complex construction consisting of seven separate but also smartly connected columns, which are designed like a human spinal column with separate, moveable vertebras. The LEAPFROG vision, an innovative concept for garment manufacturing, comprises a holistic, general production-line from single-ply cutting, automatic transport to sewing processes with robotic 3D sewing and 2D sewing machines.

2.1.1 Robotic 3D Assembly

2.1.1.1 Reasons for Robotic 3D Assembly – Automation, Quality, Innovation

Today, it is very difficult to find out where and how our clothes have been produced. Most garments travel a very long way around the whole world, before they are presented in European shops.

First reason – automation: Currently clothing production has moved to countries with low labor costs. Asian countries like China, Vietnam, Indonesia, Bangladesh or India are the sewing rooms of the world. Why? In spite of great technological advances in engineering and electronics presently the garment production is still extremely personnel dependent and therefore cost intensive. The traditional high-speed sewing machine – with manual manipulation of fabric by an operator – is with about 80% share the basic machine in garment production. State-of-the-art automatic sewing units – only available for 2D-working steps – like buttonholer, bartacker or pocket sewer represent only a part of 10–20% of current production-lines. Therefore, the caravan of the sewing industry travels around the world from one low-wage country to the next. The only way to stop the further migration of garment, textile manufacturing and associated machine building away from Western and Southern Europe is the essential automation of the extremely personnel-dependent work step "sewing".

Second reason – quality: The most common sewing quality problems like seam puckering, layer displacements or problems with product fit, are a direct result of inbuilt weaknesses and process engineering of the traditional sewing machine and applied current sewing technology. Additional manual influence and the individual skills of the sewing operator substantially characterise the product quality. A further problem – most sewing operators in low-wage production countries are semi-skilled workers without professional training.

Third reason – innovation: Robotic 3D assembly offers very interesting possibilities and potentials for high-tech and high-quality garment manufacturing. The aim is to realise technologies for efficient manufacturing solutions that allow an improved quality, cost reduction and fast response to consumer market.

2.1.1.2 Characterisation of Robotic 3D Sewing Technology

Every sewn 3D cover, e.g. jackets, trousers and most other garment as well as airbags, car seat covers for technical textiles mainly consists of 3D seams to realise the geometrical shape. Therefore opposite cutting edges of fabric – of convex and concave contour – have to be joined together. Using traditional sewing methods, this can only be realised by the manual handling of the operator during sewing. The special robotic 3D sewing technology researched and developed by Philipp Moll GmbH & Co, makes it, for the first time possible to sew 3D seams automatically (Moll, 1997; Moll, 1992; Zöll, 2003).

The 3D robotic sewing technology is specified by substantial characteristics:

- Textile cutting parts are positioned and fixed tension-free and crease-free onto a 3D mould in their spacious shape. The fabric is stationary during the sewing process without manual manipulation.
- The special sewing machine is guided and carried by an industrial robot along the spatial seam course similar to welding robots in automobile production.
- The speed of the robot and the speed of the sewing machine are constant. The manufacturing speed is about 5 m seam per minute.

- All working steps of the sewing process – positioning, sewing and transportation of fabric – are completely separated from each other. For efficient manufacturing the different working steps can take place simultaneously and be overlapped.

Therefore, important advantages of 3D robotic sewing are:

- The 3D sewing process is reproducible, automatically and independent of the skills and daily condition of a human operator.
- The automation of sewing manufacturing allows high productivity and efficiency independent of labour costs and manufacturing location.

Due to the change of processing technology (sewing machine performs only the stitching process but no transport of the fabric) the improvement of seam quality is measurable: no seam puckering, no layer displacement, constant stitch length. Furthermore, sewing material characteristics, such as surface configuration, raising lay or construction, no longer affect the sewability.

- Sewing on 3D moulds guarantees constant volume of cover, a very important criterion for garment fit.
- Cut fabric marks (absolutely necessary for manual joining) are no longer necessary, so cutting time can be reduced considerably.

2.1.2 Industrial Robot Sewing Machine

The first ideas for robotic supported sewing came from the development of a medical sewing machine. The edges of the wound (spherical seams) were closed with these new hand-guided, motor-powered medical machines. Dealing with this task, analogies to spherical sewing of textiles showed up. Consequently, with regard to automation the new sewing machine was directly developed for the use on a robot. This development of an innovative robot sewing head was the basis for the 3D robotic sewing technology, see (Zöll, 2003, 2002).

Note: All traditional sewing machines for 3D garment assembly are table bound, work in two dimensions and need an operator for handling the fabric.

The new robot sewing machine is a very compact and light device. The most tested version is the lockstitch robot sewing machine with curved needle, see Figs. 2.1 and 2.2.

The following main characteristics of the sewing machine and sewing tools are special features of the robot machine; partly they are also results of the LEAP-FROG project work:

The general stitch building process is the same as with traditional sewing. The basic difference is the very specific and miniaturised construction of the robot machine for external sewing along fabric edges. The dimensions of the sewing machine are about 200 × 150 × 110 (height, width, depth) with a weight of about 7 kg plus mini-motor. Permanent selection and testing processes of new materials and upgrades of design will help to achieve a further reduction of weight and size, which is a critical factor for the choice of the robot type. The machine is connected electrically and mechanically with the industrial robot by a coupling unit. There are different stitch types available, i.e. double lockstitch, double chain stitch and overlock stitch. In the LEAPFROG project, the double-lockstitch machine is used.

A technical challenge and fundamental criterion is the adjustment between the continuous movement of the robot and the discontinuous working process of the sewing machine. This means: During the penetration of the needle in the fabric the sewing machine is constantly moved by the robot, but the sewing tools

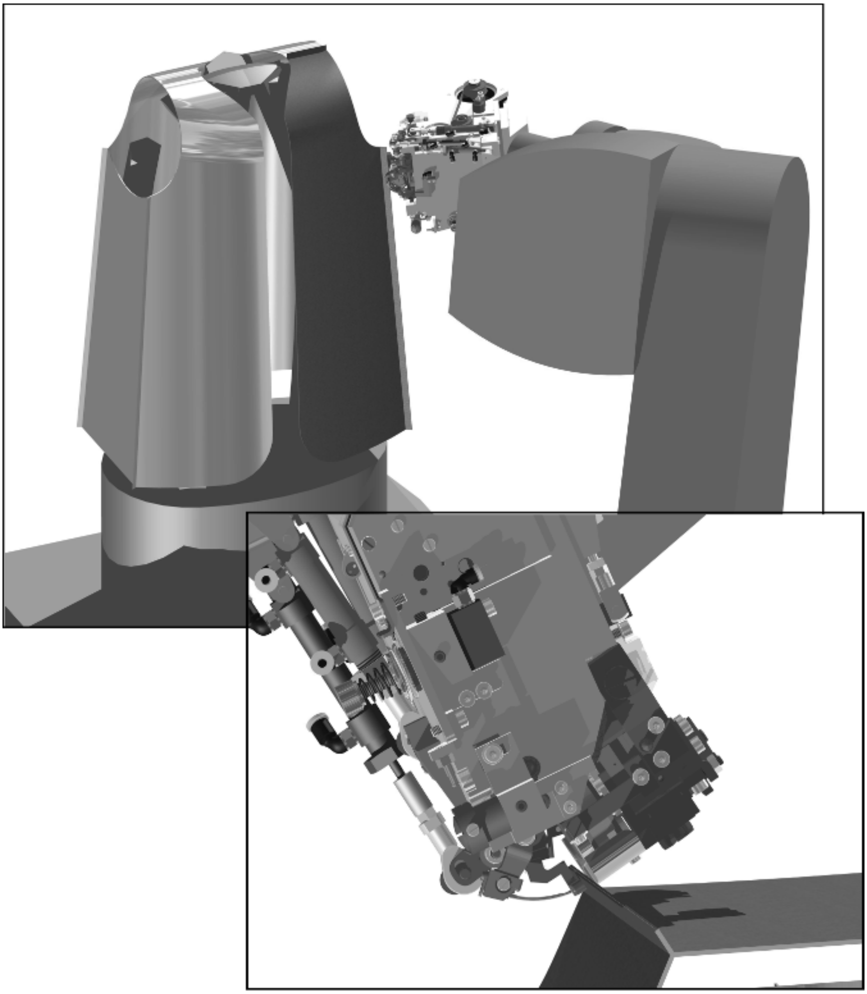


Fig. 2.1 (top left): Basic principle: Robotic 3D sewing technology/Philipp Moll GmbH & Co KG/, (bottom right): Spherically positioned fabric is assembled by robot guided sewing machine/ Philipp Moll GmbH & Co KG/

(needle, sewing foot and stitch plate) may not perform in relation to the fabric. Otherwise deformations of the seam respectively at the fabric could appear. Therefore the needle, stitch plate and sewing foot perform, in addition to their vertical movement, also a horizontal/axial movement. Furthermore, the time sequence of the vertical sewing foot movement has to be in line with the horizontal needle movement and it has to be aligned with the robot speed. This is realised by specific gear solutions.

Currently, four different gears for the movement of sewing tools are integrated in the robotic sewing machines. These are gripper-gear for rotary motion of gripper, needle lever-thread lever-gear for vertical motion of needle and thread lever, sewing foot-gear for vertical motion of sewing foot and axial thrust gear for horizontal motion of sewing tools (in coordination with the robot). The continuous optimisation of sewing kinematics is an important task. The calculations are con-

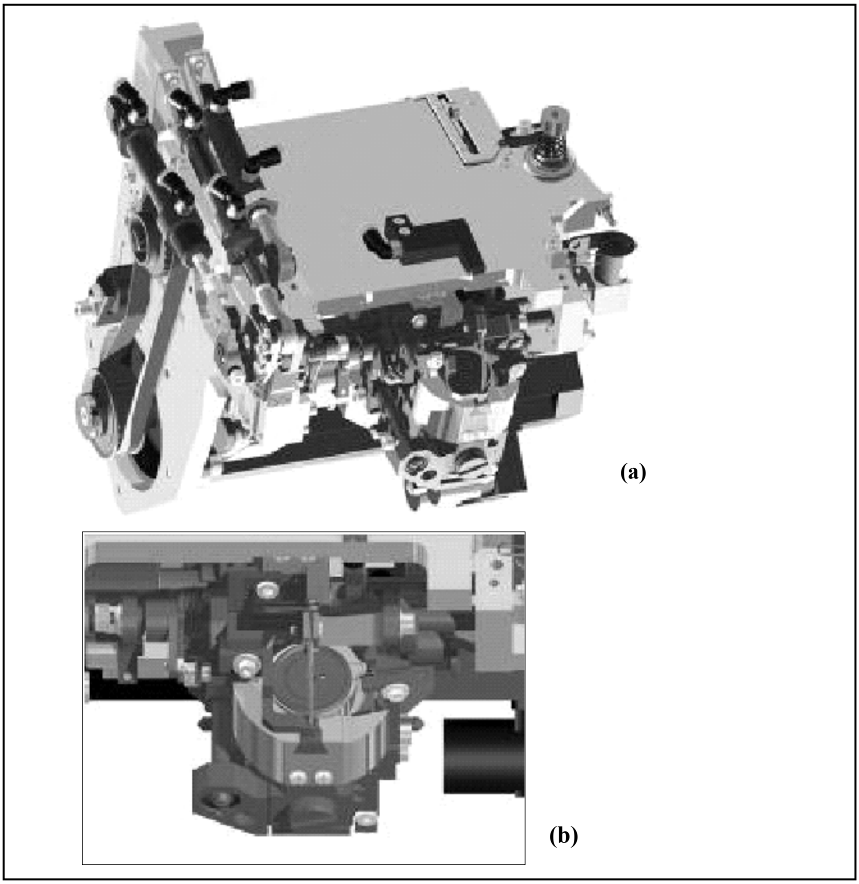


Fig. 2.2 Miniaturised robot sewing machine and tools /Philipp Moll GmbH & Co KG/ (a) Miniaturised robot sewing machine /moll/, (b) Sewing tools of robot sewing machine /moll/

tinuously updated based on analytic and computer simulations. This guarantees an excellent stitch pattern, even with difficult materials.

2.1.2.1 Sewing Tools

The special design and function of the sewing foot and stitch plate are important characteristics of the robot sewing machine. Both tools are working together as ‘fabric clamp’, but without any transport function. In contrast to traditional machines the sewing foot clamps the fabric without pressure. For safe and gentle sewing, especially with light and medium fabrics, it is helpful to use two pairs of ‘fabric clamps’ that are working alternately.

The needle for the robot machines can be straight or curved. The curved needle comes from blind stitch machines and allows sewing in a minimum distance to the 3D mould. A new design of the sewing head allows the integration of an automatic trimmer for threads cut short. The thread trimmer is positioned directly next to the gripper unit and under the thread bobbin.

For the replacement of the lower thread bobbin (double lockstitch), the sewing machine is equipped with an automatic bobbin changer. This guarantees fast and safe changing if the bobbin is empty or if it is necessary to change the thread colour.

2.1.3 Adjustable 3D Mould

The 3D mould is one of the main items of the robotic sewing system. The mould is necessary for the fixing and correct positioning of the fabric during sewing. Important characteristics of the 3D mould are (Moll and Schütte, 1997):

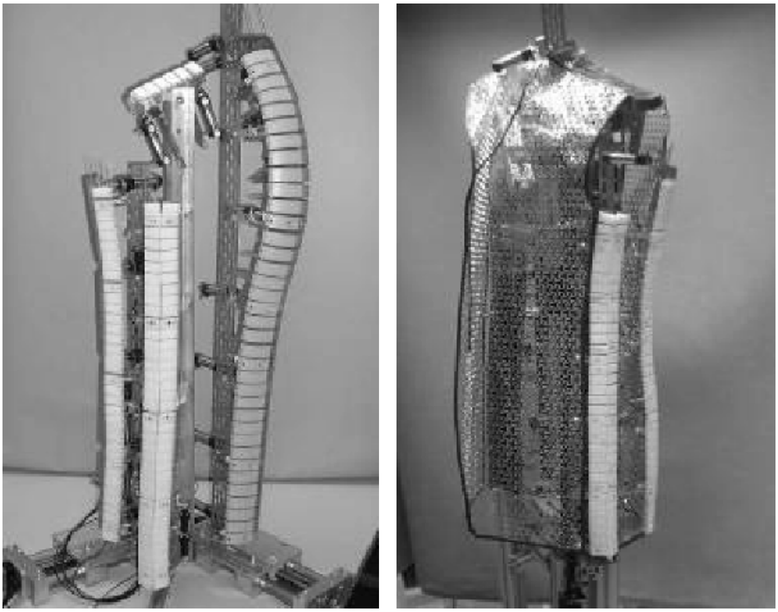
- The textile parts are placed and fixed tension free and crease free by mechanical/pneumatic units. The parts should be positioned in their ‘**ideal**’ seam line. So the correlating seam sections are in the exact position to each other and the spacious shape is formed.
- The seam allowance overlaps at the edges and is freely available for the robot sewing machine.
- The textile parts have to be fixed safely at the mould and without any displacements.
- After sewing, the sewn cover is unloaded without any difficulties.

Until the start of the LEAPFROG project, there have been only experiences in generating, design and realisation of stiff, displaceable 3D moulds for technical applications, e.g. airbags, car headrests and seats. For these technical textiles, the lot of the same model in only one size is very high and constant over a long production period of about 2 years. In contrast, garment production is characterised by small orders, permanently changing models and materials and additionally many different dress sizes. So, the great challenge within the LEAPFROG project was the development and realisation of an adjustable mould, which can adapt to different dress sizes and shapes of a garment. The chosen product was a man's jacket from sizes 48 to 56. With the robotic 3D sewing system, the main assembling seams are sewn; these are in detail two front-side seams, two rear-side seams, one rear-middle seam and two shoulder seams.

The concept of the adjustable mould for jackets is a special hollow construction consisting of seven separate columns (Moll, 2007). Every column is a single segment for one exact seam line as well as it is part of a complex mechanical/ electrical system (see Fig. 2.3). There are two different requirements for adaptation ability:

- For adapting to different dress sizes, it will (in most cases) be sufficient, to move the columns along radii in regard to the centre axis. To realise this movement, the columns are attached on a die carrier.
- For adapting to different shapes, however, the columns also need to be flexible along their own axis – they need to bend forward, backward, sideward to follow for example different shoulder or back inclinations. Therefore, the columns are designed like a human spinal column with separate vertebras that can be moved in three axes.

Every column has four different drive units: The size adjustment is realised by an adjusting mechanism in the bottom of the column. The centreboard is moved by two spindle engines. Blank sheets and conductors transmit these movements on



(a) **(b)**

Fig. 2.3 Adjustable 3D mould – prototype versions/ photos: Philipp Moll GmbH & Co KG/ (a) Columns with shape-adaption mechanism, (b) Coated columns for sewing tests the vertebras. Every blank sheet can be moved by a motor across the direction of the centreboard. This movement is also transmitted to the vertebras by the conductors. The centreboard can be moved by a cylinder in two basic positions. For forming the seam allowances, the boards move outwards for about 10 mm. For sewing, the centreboards are in their 0-position, retracted into the vertebras.

CAD data of the patterns are the only input information for the mould. Consequently, the following procedures are necessary for the generation of the 3D mould:

1. Simulation of the 3D model geometry from CAD data of 2D patterns by computer analysis and FEM modelling for each jacket size (responsible LEAPFROG partner MIRALab, University of Geneva).
2. Extrapolation of seam line-room-coordinates (*xyz*) of each jacket size simulation for the adjustment of the mould.
3. Automatic adjustment of the mould.
4. Mould concept: ‘Spinal columns’ for each seam line, very flexible and adaptable in *xyz*-directions.
5. Transfer of the 3D mould CAD-data to the robot control system and off-line robot programming (see Sect. 2.5).

2.1.4 Robotic Garment Production: from Traditional Processes to the LEAPFROG Vision

The robotic 3D sewing cell is the first step towards efficient and effective garment manufacturing that allows high-quality, personnel-independent and therefore labor-cost-independent production near end-use markets with short response time. However, it is very important not only to create automated insular solutions but to reform the whole manufacturing chain to achieve a holistic innovative production-line.

The first process stage in garment manufacturing is cutting. Presently most cutting systems work multiply with the objective of minimising the cutting costs per piece. Disadvantageous but indispensable for multiply cutting are the subsequent manual clear up, marking, arranging and bundling operations of the cut pieces. Mechanised or automatic alternative solutions for these manual procedures do not exist. The multiply cutting also bears the danger of differences in the dimensions of the cut parts between lower and upper layers of the cutting staple and between cut parts in the centre and peripheral zone of the marker.

Another weakness is that the multiply working method in cutting cannot be connected to the following working steps (fusing or sewing). The cut pieces must be separated from the staple. Presently, a reliable automation of this separating process is not realised, although perfectly working grasping systems are available (Moll and Schütte, 1997). The main reason for this problem is the process engineering of cutting: In fact, the fabric is not been cut, but ‘sawn’. As a result, the fibers at the fabric edges on directly overlaying fabrics plies are clasped or melted together. As a consequence, the cut parts may ‘stick together’ when being separated and the lower layer is misarranged. Thus, the arrangement of the staple is degraded and a manual correction is necessary. As a consequence, the bundles have to be manually separated. The time and effort for this operation are very extensive, so that benefits of the multiply cutting are partly compensated.

Additionally, results of studies show that in garment production approximately 80% of working time is used for handling and transfer of fabric parts and only 20% is used for the ‘real’ working and sewing process. The handling times include separating and bundling of parts, positioning of fabric before, during and after sewing, removal and manual transfer between working places.

The resources of the new manufacturing processes are developed under the aspects of high potential of improvement. The LEAPFROG vision – an innovative concept for garment manufacturing – comprises a holistic, general production-line from cutting and transport to the sewing process (Fig. 2.4) with the following characteristics – (Moll, 1992, 1989), (Moll and Händler, 1997):

1. fast automated single-ply cutting (optional fusing of cut parts);
2. automatic robotic pick up of fabric parts and transfer to an automatic hanging transport system;
3. sewing process with traditional sewing technique (in different automation levels) and robotic 3D assembling.

The strategy includes the following working areas (example jacket):

The first working step is the fast single-ply cutting directly from the fabric roll with minimum two cuttings heads (or four cuttings heads) followed by automated marking/labeling of cut parts. Before cutting, a camera system scans the fabric and detects (previously marked) fabric errors with their size and position. After the scan, the marker is automatically changed (according to the fabric errors), a new nesting process is carried out. Important: After single-ply cutting all parts have an exactly defined *x*-*y* position. These position data can be used throughout the whole production-line.

The fusing and defined connection of fabric with interlining is a very important and necessary part of the jacket production. In traditional production only selected cut parts are fused. It is recommend to fuse all cut parts with a conventional fusing press to avoid shrinkage of fabric during manufacturing and so to ensure optimal fit. The transfer of the cut and marked parts can directly take place from the cutting table to the fusing press. The waste-grate of the cutter is mechanically lead away (for example wound up on a separate roll).

The safe grasping of the cut pieces is done automatically by handling robots and the pieces are transferred to the hanging transport system (see Sect. 2.3). After fusing, every part is in an exactly defined *x*-*y* position. For the transport the parts should be fixed in a special carrier like a clamp or hanger. If possible, this device should not be removed during whole production process. So every part can be identified and the actual position is transmitted. A great advantage of the hanging transport is that gravity helps keeping the flexible cut parts hanging smoothly and quite plane in the clamp.

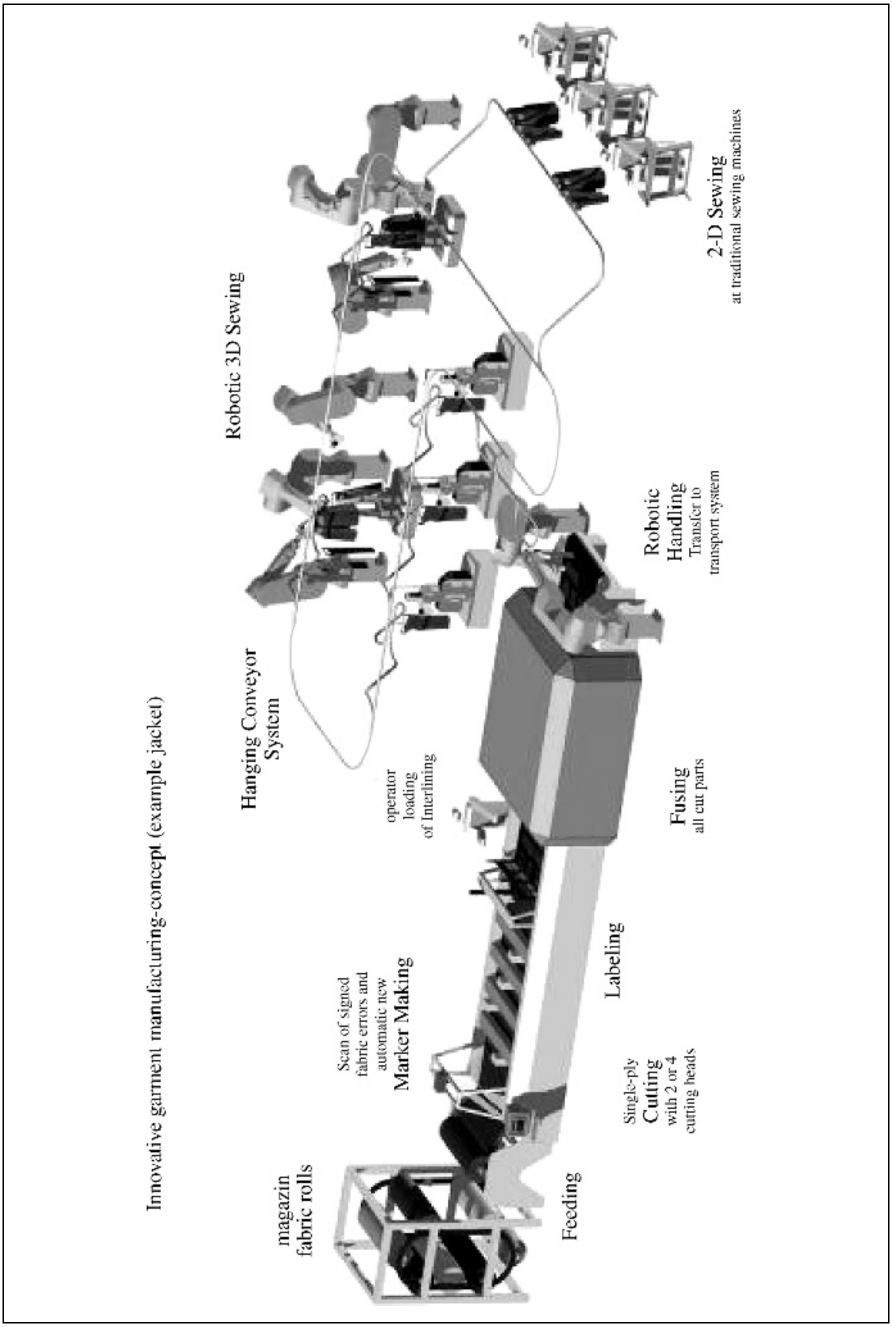


Fig. 2.4 Concept for innovative holistic manufacturing process/Philipp Moll GmbH & Co KG/

Different sewing stations that are necessary for pre-assembly and assembly are connected to the hanging transport system. The 2D sewing units, equipped with traditional sewing machines and automatic sewing stations in different automation levels, are necessary for operations like manufacturing of pockets, sewing darts, sewing of collars, buttonholes and buttons, etc.

The robotic 3D sewing cell is the core of sewing area. Current possible working operations are:

- assembling of the 3D seams of the ‘jacket-torso’, like rear-seam, side seams and shoulder seams of the outer fabric and lining;
- pre-assembly of the sleeve: 3D seams between upper- and lower-sleeve.

LEAPFROG proposes an innovative manufacturing line. The concept is built up in a modular and flexible way. The cells and components of the various working stations mostly work independently and are aiming at a high flexibility of manufacturing. This strategy offers a high potential for efficiency and quality (see Sect. 2.4).

2.2 Garment Manufacturing Simulation

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Massimo Callegari, Andrea Gabrielli, Marco Principi

Abstract Virtual reality simulation is used as an analysis support tool to introduce new disruptive technologies in garment manufacturing and is a core part of the interactive validation of design choices. The implemented garment assembly simulator has various objectives: (a) validation of the ‘holistic concept’ of the LEAPFROG manufacturing plant; (b) layout definition against realistic production data; (c) prediction of production metrics after plant realisation. Special attention has been paid to the level of adaptability and ease of maintenance: adding new resources or changing the statistics of production representative measures must require only a limited effort. Virtual-reality representation of *what–if* scenarios makes comprehensive evaluation of alternative layout solutions easier. A high degree of both epistemic and stochastic uncertainty is present as both the service/ product and the whole assembly process are rethought aiming at defining a new paradigm garment industry. This justifies a heuristic iterative approach based on human intuition aimed at optimising the layouts to reach satisfactory results according to human judgement. In order to make evaluation more objective, the possibility to cope with epistemic uncertainty is envisioned, probably substituting the human judgement only in part, introducing evidence-based techniques.

2.2.1 Introduction

Although the textile industry represents perhaps the oldest example of modern industrialisation (the first cotton mill at Cromford, Derbyshire, UK, is usually considered the first example of a modern factory), the level of manufacturing technology automation reached especially in the garment making part of the industry is far from being complete.

In particular, the final assembly of garments after the cutting of the fabric to the final sewing and finishing of the garment are currently performed through extensive intervention of human operators: this is one of the main causes of the ongoing outsourcing process in the textile and clothing industry to distribute the work according to wages and skills levels. Business success is sought, balancing added value and cost reduction, by productive decentralisation aiming at preserving quality critical jobs under direct control.

The evolution coherently moves towards flexible automation solutions by including functional robotic resources and specialised manufacturing cells as well as new production schedules assuring return on investment following the lean manufacturing concept (Acaccia et al. 2003).

This section addresses innovation based on the development of a simulator environment able to re-construct and evaluate garment manufacturing processes including traditional and new robotised devices at different levels of automation (Sepúlveda and Akin 2004).

In the following, first, new paradigms for garment manufacturing are outlined, with reference methods to establish and assess improvements; then, hybrid simulation aids are reviewed. Further the simulation environment and integrated resources and process models are illustrated. Test results generally refer to the LEAPFROG pilot case of production of high-quality men's jackets (Molfino et al. 2008).

2.2.1.1 New Garment Manufacturing Paradigm

Garments are products that must, first of all, exactly fit their user's body measurements and thereby provide satisfactory comfort. Additionally, customer data and preference input into the aesthetic design and the adaptation of functional requirements are means of increasing the utility and life cycle of the product.

The trend toward mass customisation and personalised production (Acaccia et al. 1999a) leads to a fundamental revision of material flows and factory layouts and organisation. Future factories have to be able to adjust themselves very rapidly to the customer's requirements (Qin et al. 2008). This requires short response time and a very high flexibility in structures and processes. New automation concepts are needed.

Ongoing aggressive competition on a global scale and rapid changes in process technology require creating production systems that are themselves easily upgradable and into which new technologies and new functions can be readily integrated. These conditions require a responsive new manufacturing approach that enables:

- the launch of new product models to be undertaken very quickly and rapid adjustment of the manufacturing system capacity to market demands;
- rapid integration of new functions and process technologies into existing systems; and
- easy adaptation to variable quantities and qualities of products for niche markets.

This new type of manufacturing systems will allow flexibility not only in producing a variety of parts, but also in changing the system itself. Such a system will be created using basic process modules – hardware and software – that will allow quick and reliable re-configurability to adapt to new production needs.

The *off-line re-configurability* refers to the capability to easily rearrange the manufacturing plant layout and control system for new garment needs using the plant resources and, if needed, adding additional ones; the re-configuration is facilitated both by a modular approach in the plant and resources design and by the availability of a parametric simulation environment useful for comparative evaluation of the efficiency and performances of alternative production plants. The *on-line* or *real-time re-configurability*, typical of agile systems, refers to ‘on the fly’ rearrangement capabilities of the manufacturing systems by themselves, based on a high level of intelligence and modularity embedded in the manufacturing resources and plant control system.

2.2.1.2 Role of Simulation

Taking into account the new garment manufacturing paradigm the integration of new resources and of new technologies in production systems has to be considered and evaluated. A costly trial-and-error process can be shortened by working on virtual models of the different alternative layouts of the complex mechatronic system (Bonsignorio and Molfino 2006). The role of simulation as decision support in layout and control architecture design as well as in plant management is hereafter briefly introduced.

The design of the new garment assembly plant is greatly helped (and perhaps even made possible) by the capability of virtually evaluating by simulation many alternative scenarios and solution frameworks that are based on different kinds of processes, resources and technologies at different levels of innovation. The attention is focused on a progressive development of the layout model through a what-if approach: the possible design choices are evaluated in advance against already attained performance indexes (Barton et al. 2003). A realistic simulation model can be valuable beyond the design stage: it can be a decision support tool for continuous improvement and possible re-configuration of the plant during its operative life (Michelini et al. 2001).

The dynamic evolution of the system in terms of material flow across the layout resources is driven by the routing rules determining the list of future events.

These rules interact with operational procedures to properly manage any foreseeable occurrence, such as maintenances, failures or shortages in consumables or spare parts.

Simulation provides visibility on the governing rules. The embedded knowledge coding expands on several layers, Fig. 2.5, with oriented scopes, namely:

- the facility description infers the causal relations (structural models) and judgmental frames (behavioural modes);
- the functional modelling leads to generation of the algorithmic and the heuristic blocks for the virtual-reality experimentations;
- the testing and evaluation is performed on actual production programmes by varying the governing logics on the strategic, tactical and operational horizons.

Actual simulation software includes two series of modules: the first generates the facility dynamics (structural frame); the second provides the governing logics (behavioural frame). The package assures the testing on alternative setups by simulation provided that, at the development stage, functional models are established on parametrical bases. The governing modules supply the means to evaluate flexibility effects along the long, medium or short time spans.

The simulation tool may also be used to choose the management operations by exploiting learning loops aiming at assessing the cross-coupling effects of flexibility on efficiency; these effects are related to the control operations, selected for the facility production capacity, in view of delivery schedules and due-dates (Carvalho et al. 2003). Efficiency is evaluated after collection of sufficient data, by repeated simulation tests. For capacity allocation, the control-and-management of flexibility is made up of decision options in connection, e.g., with: shop-floor logistic; operation-cycles schedules; production agendas planning; capacity requirement setting (Kurşun et al. 2007). Furthermore simulation may be successfully used as a training tool for plant operators and supervisors.

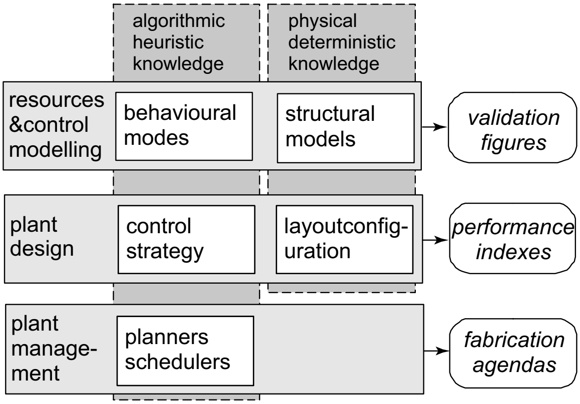


Fig. 2.5 The simulation frame architecture

2.2.2 The Developed Garment Manufacturing Simulation

Garment manufacturing plants are complex multi-agent non-linear manufacturing systems where the relation between the design parameters and the constraints cannot be expressed in a closed form (Acaccia et al. 1999b). Therefore, this is a typical case where the simulation of various alternative competing solutions can be an effective design support tool (McNally and Heavey 2004). In this case a DES (discrete-event simulation) model of a whole quality garment-manufacturing plant has been implemented and analysed. The specific simulation environment provides both a qualitative (e.g. by means of visual animation) and quantitative (e.g. by means of performance indices) verification of the possible design choices.

In order to assess the technical feasibility and advantage of introducing new robotised resources for fabric manipulation, transport and joining operations, CAE applications have been adopted to test in advance the functionality of the innovative resources and their integration within the overall plant layout. To this aim, a detailed 3D physics-based multibody (PBMS) simulator has been developed.

The discrete-event simulation is helpful in drafting the operational logics for the management of material flow across the plant, while continuous-time models are useful to define the kinematics of standalone mechanisms as well as to study the interaction between the master devices and the other resources of the plant.

The run-time interfacing of the DES and PBMS models has proven to be very important for the detection of the functionalities that the control architecture must provide to make the innovative production agents cooperate. The result of this integrated approach is a realistic simulation model where the flows of materials is governed by a discrete events logic and the compilation of the list of future events depends on the results of physics-based simulation, mainly in terms of the duration of processes and the kind of produced items.

2.2.2.1 Multi-Agent Discrete-Event Simulation Model

The garment-manufacturing plant is modelled as a collection of agents that exert a reciprocal influence or interaction during a certain time span in order to achieve some measurable results that are of interest for the investigation (Moss and Davidsson 2001).

Agents require an explicit representation in the model, since they concur to define the results. They can be either production resources, parts, operations to be implemented, transport units. An effective and rational model shall attain a certain grade of simplification in representing the real system (McNally and Heavey 2004). The choice of the items to be included has a deep impact and must set a correct trade-off between the model's representativeness and its simplicity.

The evolution of the model is determined by the periodic evaluation of its constitutive logic and algebraic statements; the scanning of the schedule of the future events reproduces the occurrence of a sequence of events according to pre-defined simulation rules. The discrete events simulation (variable time between two consequent events) is a stochastic process that cannot monitor any physical attribute of the system entities and needs to run many simulation runs for collecting significant statistically meaningful data.

The productive facilities in garment-manufacturing plants are classified including new purposely developed robotic resources: this leads to the definition of the corresponding element classes. Each family of entities is displayed through an easily recognisable 3D mock-up.

The adopted simulation tool offers to the designer great flexibility in coding customised behavioural rules or modifying existing ones in order to faithfully represent the response of the system to the events occurring during the simulation. Some specific rules for the routing of the parts are required because different agents will follow different paths throughout the layout's functional areas.

The PnF class of transport systems presents a high level of adaptability to the recalled new paradigm of garment manufacturing and is selected as an example of the presentation of transport logics modelling and simulation.

The simulation model emulates the complex behaviour of the PnF transport system by means of decision units located on specific points of the layout that are critical for the plant/process evolution such as bifurcations and operative cells. Each decision unit is equipped with suitable virtual sensors to recognise the resources state and with the same logic that will be implemented in the physical word by a distributed intelligence device that must communicate with a central supervisor.

The execution of a routing operation depends on the verification of several conditions about the availability of parts, on the status of the destination, on the requirements of the current process. All parts of the same fabric belonging to the same garment inherit from it a common univocal ID that allows recognising and reassembling them within the production plant.

The transport system layout is made up of a main track on which a suitable number of carriers run to serve the production shops; many derivation segments allow both the loading/unloading of the carriers to/from the work cells and the dynamic buffering of the parts. The carriers waiting for a given operation accumulate in these pits and don't interfere with the flow of carriers on the main rail.

Since this power and free (PnF) system plays as a dynamic buffering capacity, this solution avoids almost everywhere the use of the conventional buffer elements, thus reducing the amount of work in progress in the system. At those points where the risk of long queues potentially hindering the flow on the main rail is higher, a control over the number of waiting carriers is introduced. A more complex transport system layout with branches and bypasses allows a more agile service but the number of decision units grows and logics is more complex, given the physical constraints and the number of events occurring at the same time.

2.2.2.2 Physical Resources Model

In order to implement and use simulation aids to test in advance the functionality of the innovative LEAPFROG resources and their integration within garment-manufacturing plants, detailed, simulation modules have been developed by using 3D physics-based models and manufacturing-oriented simulation language. The detailed investigation of the novel manufacturing processes is greatly simplified by specific features, in particular:

- estimations of the productivity and duration of novel processes, for which past references are not available, is precious information for the design of the whole plant;
- the simultaneous simulation of complex multi-body mechanisms allows an easy check for near-to-collision and workspace constrains, and aids in the planning of collision-free paths;
- the capability to test the real control logic on a virtual fully functional plant helps the designer and the manager of the plant in selecting the suitable control features and strategies;
- ergonomics and labour-effort analyses are helpful to assess in advance excessive workloads for the human operators.

In the following, the generic robotic agent model and its main procedure are introduced as an example.

Robotic Agent Physics-Based Model

The 3D model of a simple chain robotic agent can be purposely designed from scratch or may be retrieved from a library of standard commercial devices and, if needed, modified. The simulation kernel deals with parametric formulations of the mechanisms' kinematics and reference frames, so that any custom realisation of a featured device is automatically supported.

A complex mechanism can be designed by assembling different simple chain devices through either revolution or prismatic joints defining the reference frame around which the first relative movement takes place and the effective direction of the joint constraint. Mathematic formulation of the joint's law of motion is then given. In the case of parallel kinematic chains or cam coupling, the programming of a specific kinematic routine is required.

The definition of all the degrees of freedom makes the jogging of the robot in the joint space feasible, but does not provide the solution of the inverse kinematic problem, so that the path planning in the jogging in the operative space is not feasible. The purpose of inverse kinematics is to compute a set of joint angles that satisfies the desired path point coordinates. The inverse kinematic model has to be defined and solved for each point during the motion generation. Different solving methods may be adopted, depending on the difficulty of the model and on the required accuracy.

The programming of an agent task requires indeed the definition of the homing procedure, of the frame(s) representing the effective tool(s) working point(s), of the workpieces' reference systems, and of the I/O communication signals that would eventually be used to coordinate the cooperation of several agents.

By default, all agents are placed at world references frame as they are imported, and are all physically independent, that is to say that they do not interact or collide, until the virtual mechanical and logical connections are established. This is done in the so-called ‘workcell editor’ environment, where agents are positioned as for the workcell’s detailed layout design, and the tool devices are mounted on their master agents. The active agents keep their mobility prerogatives once attached to their frame. Their motion is indeed planned with respect to a mobile frame on the surface of the parent agent. An example application is the grasping device mounted on a robot.

Main Robotic Agent Procedures

In the simulator, the procedures referring to an agent made by more than one device can be written in one file that is subdivided in as many sections as the number of programmed devices. In the case of agents that cooperate in a work cell the chart program is split into different sections corresponding to the number of different resources involved.

The instructions featured in the chart program can be split in two classes: Graphic Simulation Language (GSL) and Command Line Interpreter (CLI) instructions. The first class instructions define the specific actions that are to take place when the instruction is executed, for instance, moving the robot, setting an output, changing data or jumping within the program. This language incorporates all the commonly used conventions of high-level computer languages with specific enhancements for agent motion and simulation. The second one is a batch language that manages commands involved with the configuration of the visual characteristics and parameters of the agents and the simulation environment.

Referring to a generic robotic work cell the robot is the main agent that coordinates the operations of all other agents of the cell by means of I/O signals and acquires external data. Its work program is coded in specific procedures, com-

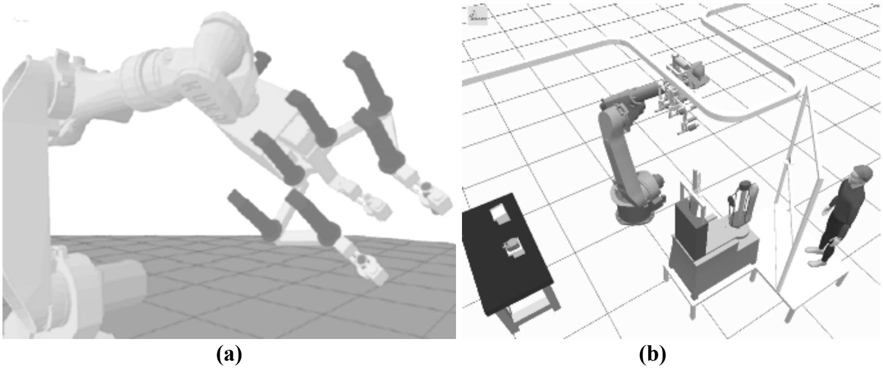

(a) (b)

Fig. 2.6 (a) An agent made by a serial chain robot and a branched-chain grasping device; (b) a multi-agent work cell posed by elementary action subprocedures, that start and are executed as specific events taken in charge by the discrete events simulation model happen. The procedure is run while the enabling conditions hold.

First, calibration and initialisation tasks are simulated, then the sequence of operative tasks is launched checking time by time the actual constraints generated within the work cell or by other agents working externally but within the plant. Logic variables are used to consent or interrupt the task execution and to arrange the conditions for multi-agents synchronous tasks (Moss and Davidsson 2001). The re-setting of all I/O channels concludes the procedure and the manipulator ends the procedure by moving back home.

2.2.2.3 The Integrated Simulation Environment

The run-time interfacing of the DES and PBMS models is useful for the validation of the design concepts, when applied to a realistic production metrics, and it is very important for the detection of the functionalities that the control architecture must make the innovative production agents cooperate.

The mechanism that enables this integration is the communication of data and signals over the operative system's logical ports (sockets). Both the used DES and PBMS software allow the socket communication and the object-oriented simulation control languages to provide the same instructions and methods to set the communication. By communicating through different logical ports with different IDs, the same server session is able to correctly route the messages among many client-simulation sessions. During a hybrid integrated simulation session many interactions are generated between the QUEST and IGRIP processes; the DES simulates and communicates the flows of materials and the status of all production actors to the PMBS, which tests the breakthrough manufacturing processes against realistic metrics of the resources. In the same way, the execution times and the kind of the produced items that result from physics-based simulation are scheduled in the list of future events, thus influencing the operative strategy of the whole plant.

2.2.3 Simulation Tests and Results

The production schedule is generated through a suitable database from realistic production information. Thanks to the modularity of this approach a database of all relevant parameters has been set and specific input masks have been introduced in order to make the data input more intuitive to the end-users.

In the specific DES simulation environment the quantities and features of resources in a model can be modified through the batch processing of a configuration file. An application automates the process, by progressively generating a sequence of configurations that are closer and closer to an optimal solution: the optimisation mechanism relies on the ‘scatter search’ meta-heuristic approach and is applied to the output of each simulation run. The user must input a tentative solution, define the optimisation drivers, the lower and upper bounds for the parameters to be optimised, that can be either discrete or continuous, and set one or more algebraic constraints on their values.

An articulated test campaign has been focused on the influence of the dimensions of the lots making up the production orders. Along with the extreme conditions of unitary and mass production, the management of lots with mean dimensions of 2, 5, 10, 20 and 50 items (with 20% standard deviation) was simulated to determine the effects on product throughput and plant productivity. The number of jackets produced in 40 hours in steady conditions is the driver of the layout performance optimisation, under the restraint of a fixed maximum amount of all the resources (manual and fixed automation stations) implemented in the layout.

The optimisation study helps also to lay out the most suitable sets of resources for a certain production type, or even gives indication about the dynamic allocations of the production agents (i.e. how much and where employing highly skilled human ‘jolly’ resources) for plants that should manage production schedules with non-uniform batches dimensions. Referring to this aspect, a study was performed on the optimal number of carriers in function of the lot sizes (see Table 2.1): the results shows that a dynamic carrier reservoir system is helpful if facing meaningful variability on the composition of the orders.

Garment assembly cell: The smaller is the mean lot size, the more the production is paced by the parts sorting process that causes the saturation of the buffering capacity of the conveyor rings.

The optimisation study improved the utilisation rates of resources too, as shown by the diagram in Fig. 2.7b: although the empirical refinement process led to saturation of the productive capacity of a high percentage of resources, through the heuristic search algorithm a more uniform and effective distribution was attained.

The optimisation study is able to suggest a better production organisation, by providing an holistic approach that goes beyond the performance analysis of single resources. An example of this sensitive analysis is clarified by analysing the diagram in Fig. 2.8a, reports the mean resource utilisation in two different optimisation experiments.

The two groups differ for the adoption of two or three cutting lines. In both cases, the mean productivity of cutting lines increases with the mean batch size, since the quicker the sorting process in the garment assembly cell, the higher is the frequency of carriers available to be loaded. Their productive capacity is far from

Table 2.1 Optimal number of carriers for different lots mean sizes

Mean lot size (20% st. dev)	1	5	20	50	100
Optimal number of carriers	110	129	142	142	147

being saturated, hence they do not represent a bottleneck for the production-line, as the increased productivity of the garment assembly cells shows as well. The utilisation rate of the sewing area is decreasing when only two lines are used: with large batches, this layout configuration suffers from the poor parallelisation of the work burden, calling for a rethinking of plant logistics.

This example explains as the simulation model can support the enterprise's choices in the design of the plant, visualising the conditions under which the adoption of additional capital-intensive resources (cutting lines, GAC) becomes profitable: Fig. 2.8b suggest that a plant where the maximum expected dimension of production lots is 10, would hardly benefit from utilisation of a third cutting line.

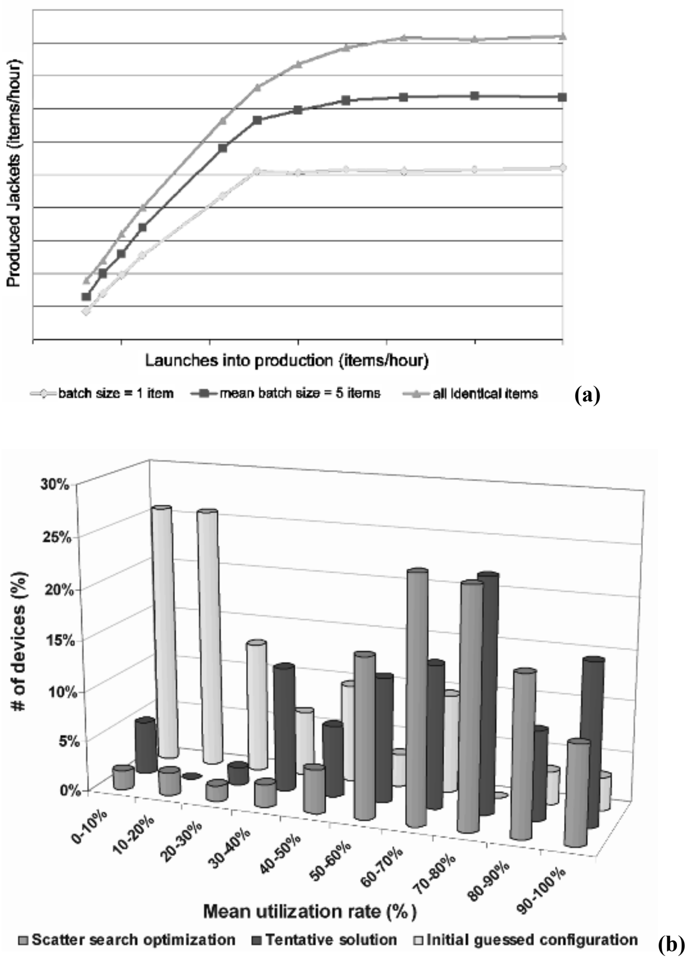


Fig. 2.7 (a) Plant productivity as a function of mean lot size (with optimal number of carriers); (b) Mean utilisation before and after the optimisation

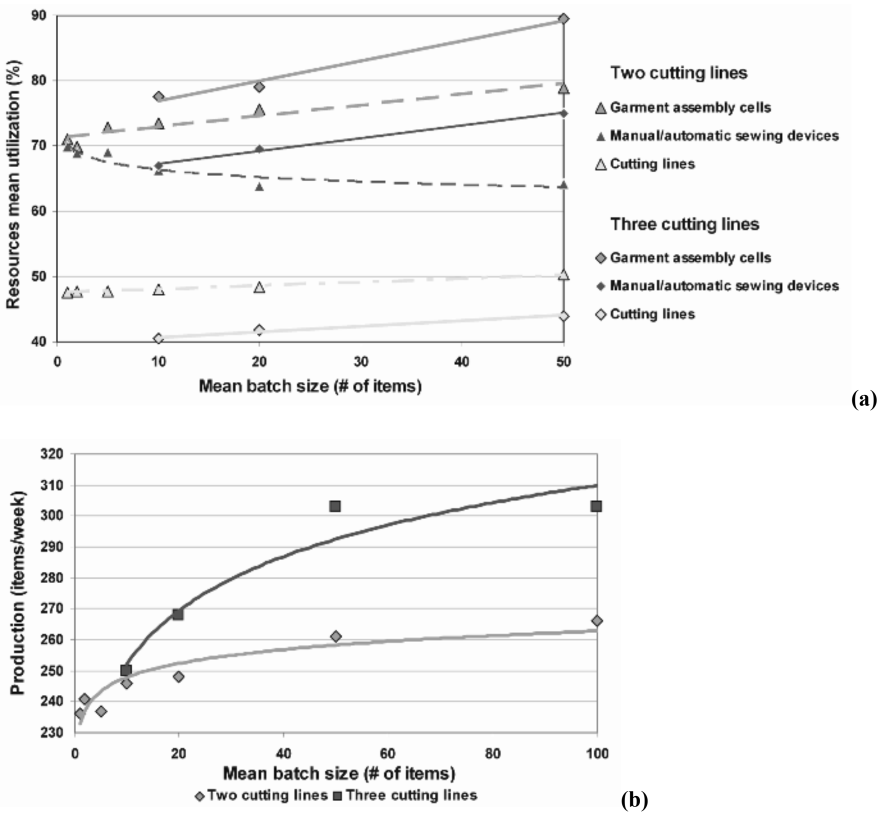


Fig. 2.8 (a) Optimal utilisation of resources as the batch size changes; (b) Optimal plant throughput as a function of batch size

2.2.4 Conclusions

This section introduces a new simulator environment for intelligent clothing manufacture. The competition between enterprises resorts to the process-added value of actually sold apparel, rather than to large products batches, requiring to run after buyers, with advertising or lower sale prices. High-standing clothes are noteworthy, as clients require personalised quality and quick service. The discussion offers hints to look after the integrated manufacturing approach and the influence on the process efficiency of new robotised resources developed within the LEAPFROG integrated project is specifically dealt with. The process description is based on a modular lay-out, to separate the effect of influence quantities and to investigate details, preserving the overall view of the process evolution.

Today, the clothing industry is highly labour-intensive and relies extensively on human-operators versatility to modify production, while the process progresses; this possibly reduces the benefit of intelligent manufacturing, based on the concurrent run of material and information flows for adaptive flexibility (Bruzzone et al., 2003).

The example discussion shows that flexible automation can deal with the foregoing information on self-sufficient bases; actually, the benefits depend on a large number of cross-related facts and actual implementations, hard to be fixed, remain out of the reach of front-end operators. The area of high-standing garments, satisfying varying market requests, is a sample case where automation provides critical support for quality certification.

The changes towards flexible lean automation, however, need to be investigated in terms of realistic system behaviour and expected economic returns; simulation studies that integrate discrete events and 3D physics-based multi-body models are helpful to compare competing alternatives referring to actual production contexts and, moreover, to provide explanatory examples with support immediately related to sets of feasible implementations (Shreck, 2002).

2.3 Robotic Soft Material Handling

Rezia Molfino, Matteo Zoppi, Enrico Carca

Abstract The lack in available technology and systems for flexible handling of limp, synthetic and natural materials is one of the major bottlenecks to the extended robotisation of the high human-labor-intensive sectors such as clothing and footwear manufacturing. Several handling operations occur along the manufacturing process of these goods. The majority of these operations today is carried out by manual labour and none of the past attempts at innovating the overall manufacturing system by introducing new processes and technologies related to fabric shaping, joining or finishing succeeded in completely eliminating handling tasks in an economic way. Typical handling tasks are picking and orderly placing of fabric parts. Main concerns are: robust and reliable grasping of limp parts without damages and accurate positioning for the following manufacturing operations guaranteeing the quality of the final product. Cutting table unloading may be considered a reference task because it is a necessary step in an automated garment manufacturing process today and it involves all main handling issues: picking from flat, lifting up, displacing, releasing with required position accuracy. The focus is put on high-quality fabrics that are often very light and delicate and which have to meet the most stringent quality requirements. The development case considered is the production of jackets for formal men's suits. A fully automatic cutting table unloading cell has been developed and is being industrially demonstrated. As part of it, the new concept of a re-configurable hanger that holds the individual fabric item during transportation to the following manufacturing stations is realised. Unloading of the cutting table and loading of the hanger are performed by a robot equipped with an innovative re-configurable gripper that picks and lifts up the cut part and transfers it to the hanger in one working cycle.

2.3.1 Introduction

The low level of automation in the clothing industry is mainly caused by the particular characteristics of the material to be handled. The fabric is a limp and soft material that does not have its own well-defined shape and at the same time requires precision and forethought during the cut, transport and sewing operations (Tait 1996). For this reason while robotic manipulation of rigid material is successfully realised and working in many industrial sectors, the difficulties in handling textiles and soft material in general, has so far largely prevented the automation of the related manufacturing processes (Costo 2002).

The basic technology utilised in the production cycle of the clothing industry is in many parts unchanged from fifty years ago. The only sections benefitting from automation are the fabric warehouses and the cutting processes. But in this two sections the fabrics are rolled up (warehouse) or stretched out in a bi-dimensional configuration while laid down on the cutting table where shapes are kept with the help of vacuum (cutting table). The automatic handling in these two configurations is easier compared to three-dimensional configurations.

In clothing production, the transformation of the fabric into garment is realised by resources that directly modify the material and resources that are needed but do not add value to the product. We indicate as primary the first category and secondary the second ones.

Analysing the traditional process flow, weak points are singled out in the sewing phases where the components of the same garment follow different paths to make subassemblies before to be joined together, requiring a great effort in logistics and wide use of secondary resources. This work flow is really not suitable for mass-customised production, is manual intensive, difficult to monitor and subject to errors (see Sect. 2.4).

In the past decades automation and digital design integration renewed the cutting process but the following primary and secondary processes are very hard to automate because accurate and reliable fabric handling is an extremely difficult problem to solve (Cutkosky 1985).

One of the LEAPFROG paradigms is to enable automated 3D clothing assembly based on advanced robotics and innovative joining techniques. This requires innovative fast and highly reconfigurable robotic resources with as yet unseen dexterity, cooperation ability and robustness in handling and working with limp materials. To this aim the garment manufacturing system is re-engineered by rethinking and radically redesigning the overall process and integrating new resources.

The process starts with automated cutting: the table receives the fabric from the automated store and cut it in the desired shapes. Cutting is performed on a 2D surface by a cutting head moved, e.g. by a Cartesian manipulator. After cutting, the parts are picked up by an unloading system and transferred to the conveyor (transport) system. The shapes, dimensions and material properties of the parts are different for every garment and this requires a re-configurable device (Taylor 1999). This operation is currently performed by a human operator whose task would then be assumed by the robotic system. The conveyor moves the parts to the assembly cell with some possible intermediate stops for manufacturing operations, e.g. attachment of pockets and partial finishing. In the assembly cell the fabric items composing the jacket are suitably positioned on a 3D size-adjustable mould and a sewing machine guided by a service robot executes the sewing operations. This section focuses on the design and development of robotic devices for fabric items handling within the clothing manufacturing process with particular reference to the formal men's jacket.

2.3.2 Soft Material Handling Tasks Requirements

A grasping device is designed to work in a given environment to perform a specific set of tasks. Each handling task comprises a picking phase, a transportation and/or handling phase and a placing phase: the handling device has to be designed to efficiently and robustly perform these subtasks (Carca et al. 2008).

The primary requirements are quite general (i.e. execution of a given set of tasks) and the solutions satisfying these requirements are several. Task-oriented design becomes a winning strategy. At the same time the high risk of ineffective or uneconomic solutions can be reduced by extensive use of simulation and virtual prototyping (Molfino and Zoppi 2003).

Hereafter, we will analyse the more common picking and placing environments for near-2D limp material. We focus on 2D single-layer soft material handling.

2.3.2.1 Typical Picking Environments

Limp sheets in general lay down on the flat stiff surface of a table, a carpet or a conveyor.

Sometimes in typical automated manufacturing environment limp items are moved from one section to the next by a hanging conveyor system: each item is held by a hanger equipped with pincers. Accordingly the grasping device carrying out automatic table unloading shall be designed to connect the item to the hanger after having picked it up from the table. This involves a transfer that makes it difficult to guarantee accurate geometric positioning of the item with respect to the hanger during the whole cycle.

Sometimes, as in the case of garment and shoe manufacturing, limp items or their subassemblies have to be released on a mannequin or mould. In these cases attention has to be paid to the structure supporting the item and to the consequent requirements on the picking operations.

All the cases considered above refer to environments structured for automated manufacturing. In the case of traditional manufacturing or domotics the environment is not structured and usually limp items are gathered in a bundle or in a heap. In this case picking has to be guided by sensors (e.g. vision or tactile).

2.3.2.2 Typical Placing Environments

Limiting our analysis to near bi-dimensional items, the following main placing cases can be distinguished: placing the item unfolded on a rigid flat surface orienting it if needed; placing the item on a 3D surface (e.g. mould or mannequin) on which the item assumes a 3D shape; hanging the item to a hanger or similar device that will move it to other places; throwing the item on a heap or bundle.

These cases present different needs and result in different requirements for the grasping device.

The first case (placement unfolded on a 2D surface) is satisfied by an articulated grasping device picking the item along one edge at a suitable number of points. In the case of big items the number of picking points may be very high making the grasping device complex. With regular item shapes a low number of points can suffice but the grasping device has to use gravity or to cooperate with a conveyor for correct placing.

The case of placement on a 3D surface is more complex and no effective solutions have been proposed until now. Several degrees of freedom and a high level of coordination are required (humans use two hands). A grasping device with these characteristics shall be re-configurable and quite complex to provide robust results.

The case of loading on a hanger involves the ability to handle the hanger together with the item, set it in a way to receive the item and carry out the loading operation.

The last case of throwing on a heap does not present a problem.

2.3.2.3 Reference Handling Task: Cutting-Table Unloading

We consider limp sheets laid down on the flat stiff surface of a cutting table. After cutting, the items are adjacent to each other and the picking of one item may cause the disarranging of the adjacent ones, so, if exteroceptive sensors are not used, the positions of items unexpectedly moved are lost. In this situation picking has to be carried out from above by using suitable physical principles and lifting technologies.

The transfer of each part to the transportation system is carried out by the robot with grasping device and the part is transported in a hanging configuration.

When cutting is over, the carpet moves the templates into the workspace of a robot carrying the grasping device. The parts are individually picked up and hung on the transport system accordingly to the actual table unloading strategy.

The main requirements for the grasping device are a very high MTBF (mean time between failure) of five years continued use, 15 kg maximum mass, high acceleration and velocity to make the grasping cycle time compatible with average cutting times.

2.3.3 Design Methodology

2.3.3.1 Multi-Point Grasping Paradigm

The multiplicity of the shapes, sizes and tasks together with the difference of the materials requires very flexible and dexterous grasping mechanisms. By mimicking the highest level of the human-handling capabilities, grasping articulated mechanisms equipped with a number of picking modules are proposed. They are able to re-configure positioning the picking modules in a way suitable for the actual item/task. The re-configuration can be done on-line in real time by the actuation of the interested degrees of freedom.

The synthesis of the handling mechanism has to comply with the functional criteria derived from the task specifications and to the general manufacturing paradigms of low life cycle cost and fast working cycle (Cavallo et al. 2001). From this point of view different branched articulated chains have to be compared and the simplicity of the architecture providing for high functional reliability is counterweighted by the absence of singularities, smoothed fast moving and handling robustness. The examples described later will show the application of these criteria.

The proposed methodology allows us to design handling devices by decoupling the adaptation to the material from the adaptation to the shape and size of the object to be handled. The picking module has to be chosen to guarantee grasping robustness and it is mainly influenced by the material mass and surface properties, while the mechanism architecture is in charge of the range of re-configurability to comply with different sizes and shapes of the pieces (Kolluru et al. 2002).

2.3.3.2 Modularity Paradigm

One of the main design methodologies adopted is modularity. The motivation of modularisation of the grasping device is to meet the ever-changing demand for the needs of the product, in particular to rapidly achieve maximal flexibility (Molfino and Zoppi 2005). The modularity allows realisation of a diverse range of grasping tools starting from and assembling together a suitable number of developed modular components (Molfino et al. 2004).

The higher the level of innovation and risk required, the greater is the attention to be put on the modules and modular architecture development. A virtual mock-up of the modules and simulation/ animation tests are useful for a preliminary a priori knowledge-based validation of the design. Later, a physical prototype is realised to verify all the operative aspects that are difficult to be modelled and validated through simulation. For example, empirical knowledge is required in order to set useful friction and vacuum parameters to evaluate the capability and effectiveness of the module to grasp and move porous material under high speed and acceleration.

2.3.4 A New Concept Handling Robotic System

This section presents the new concept handling system purposely designed to pick, lift, handle and release in a hanging configuration the cut fabric items to a transportation carrier: it is composed of a passive re-configurable hanger (RH) and the reconfigurable grasping device (RGD) that integrates the picking modules (GPM). The reconfigurable grasping device should be carried and operated by a service robot able to move the gripper and control its orientation.

As first we have to detail the handling strategy. Actions to be executed include the picking of a free hanger (preferably from the same conveyor moving the parts), picking of a part, application of the hanger to the part, release of the loaded hanger onto the conveyor.

The single parts moving into the manufacturing plant need to be kept flat and in a well-defined position. This goal is easily reached by pre-defining suitable picking points for each part ensuring its vertical arrangement flat and without wrinkles exploiting the gravity force. We call these points precision points. The concept applies independently of the type of clamping/holding technology adopted, provided that it generates a localised joining. For the men’s jacket production considered so far, three picking points are sufficient to guarantee the correct handling of all types of cut parts. The coordinates of the precision points (Dai and Rees Jones 2002) are known in the hanger reference frame and they are used as the interface between the parts and the manufacturing facilities. The error boundary assumed for these points is a circle 1 mm in diameter around the ideal point locations.

2.3.4.1 Reconfigurable Hanger

The re-configurable hanger is a passive, simple and cheap tool according to the high number of units present in the plant.

Fabric is blocked by the re-configurable hanger by means of three mechanical pincers (clamps). The mechanism carrying each clamp should be able to move the grasping point in the plane of the part (in the workspace boundaries). The total needed degrees of freedom (dof) are 6 but can be reduced to 5 when accepting to have one grasping point adjustable in one direction only.

In fact, the geometry of the parts suggests that the central clamp might move only in one direction while the other two points should move in the plane of the part. The planar bond for the lateral clamps may be obtained by several different kinematics architectures. An RP finger (composed of a revolute and a prismatic joint) with the axis of the R joint orthogonal to the plane of the part and the direction of the P orthogonal to the axis of the R satisfies the requirement for the lateral points. The central point is connected to the frame of the hanger by a P joint.

The hanger proposed (Fig. 2.9a) comprises a body, three arms each ending with a clamp. Each clamp is long and thin to realise a double finger-tip grasp (Fig. 2.9b);

(a) (b) (c)

Fig. 2.9 Reconfigurable hanger: (a) prototype, (b) clamps and (c) electric circuit

it comprises a base with a rubber pad at the tip and a leaf spring with a needle pressing the clamped part against the rubber pad and locking it in position by means of the needle.

Grasping Kinematics

Let q denotes the gripper internal coordinates; u, the object location and attitude. Within a first-order approximation along smooth paths, $\delta\mathbf{q} = \dot{\mathbf{q}}\delta t$, and $\delta\mathbf{u} = \dot{\mathbf{u}}\delta t$ specify the local motion. The vector model describing basic handling when contacts hold, considering gravity and inertial forces, is:

$$\mathbf{HG}^T\dot{\mathbf{u}} - \mathbf{HJ}\dot{\mathbf{q}} = 0 \tag{2.1}$$

where **H** is a matrix selecting the holding contacts; **G** is the grasp transform, providing the object local posture setting; **J** is the gripper transform, specifying the local Jacobian matrix of fingers lay-out.

The contact establishes non-holonomic, unilateral constraints, that in general are modelled as:

$$C(\mathbf{q}, \dot{\mathbf{q}}, \mathbf{u}, \dot{\mathbf{u}}) \leq 0 \tag{2.2}$$

where inequality shows that contact can be lost.

Several contact types are used. In our case the contact-area (soft-finger) is considered and the resultant forces are integrated from local pressures distributions.

Friction and Compliance Effects

Our grasp uses area-frictional contacts and needles, yielding to comparatively high tangential and small twist components. A coarse analysis generally deals with point contact with friction, and for safe seizing, the tangential components are supposed to remain sufficiently inside the friction cone, while the twist components are properly neglected. The study is based on empirical evidence. The needles provide further contact to ensure no tangential displacement occurs.

During the early design steps, theoretical assumptions were introduced. Hertzian contact and tribology models demonstrated to be inadequate for robotic grasp, as small finger displacements apply through driven compliant chains. Schematic guesses were worked out with soft-finger contact type (compliance concentrates at finger-grasp regions). Preliminary analyses demonstrated that friction deserves great attention, and creep and viscoelastic phenomena also needs to be included to assess the coupling at the soft contact.

The robotic grasping of soft 2D parts cannot resort to form-closure typical of rigid parts and is based on force-closure. These defective grasps are generally slightly sensitive to posture errors and less affected by external disturbances, but require higher interfacing forces (with greater stress and strain distributions), with damaging risk for the handled items.

Dynamics and Stability

Force-closure does not assure stability, namely, strict local minimum of the potential energy (or Lyapunov functional), unless compliance and damping effects are fully accounted for. However, current investigations mainly address conservative systems and try to get rid of local maximum or non-defined settings, due to the intuitive guess that they might be risky, in front of non-holonomic, unilateral constraints. The inclusion of control loops is an intriguing research field, requiring fully developed non-conservative models.

A picked object shall have safe and robust seizure. A minimum grasp matrix provides a measure of posture accuracy. However, defective grasp allows error insensitivity and enhanced stability, with poor knowledge of actual interface setting. Calculation of the contact forces (Salisbury and Craig 1982) was accomplished in static conditions, including the friction effects with the multi points contact assumption.

Clamp Actuation

Each clamp is endowed with a shape-memory alloy (SMA) spring actuator to lift up the leaf spring and open the clamp (Sreekumar 2007). Electrical current flows through the SMA spring along the two sticks of the hanger arm.

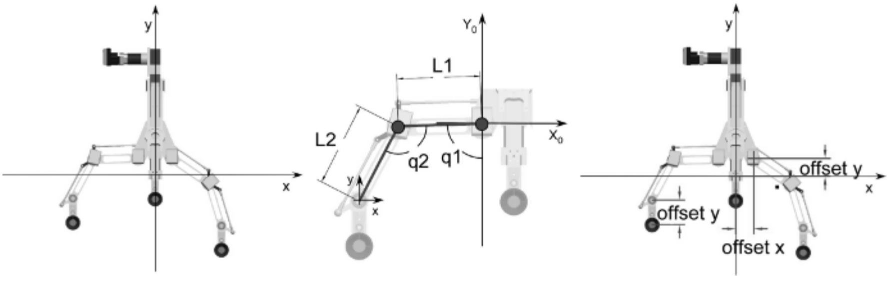
The SMA springs actuating the clamps are connected in series between the two sides of the hanger. Each hanger arm has two rods in electric connection with the two extremities of the corresponding clamp spring. Each rod is in contact with one end of a flat electric circuit in the hanger frame realising by the Joule effect the independent actuation of the clamps. The closing operation is made by a forced air cooling that flows directly on the SMA spring.

2.3.4.2 Grasping Device

The grasping device has the tasks to: re-configure the RH; pick, lift and insert the fabric item in the pincers of the hanger. The architecture is selected accordingly and comprises a branched mechanism with three planar arms, two lateral and one central. A grasping module is placed at the tip of each arm. The hanger connects at a docking station on the bottom.

The central arm can only translate in a fixed direction.

The two lateral arms have two degrees of freedom each and the grasping module is maintained parallel to the central arm by a double 4-bar linkage. A schematic is shown in Fig. 2.10a.



(a) **(b)** **(c)**

Fig. 2.10 (a) Schematic of the grasping device, (b) main parameters and (c) off-sets

Kinematic Model

The kinematics equations for the lateral arm are:

$$\begin{aligned} x &= L_2 \cos(q_1 + q_2) + L_1 \cos(q_1) \\ y &= L_2 \sin(q_1 + q_2) + L_1 \sin(q_1) \end{aligned} \tag{2.3}$$

Using trigonometric relations we obtain:

$$\begin{aligned} \cos(q_2) &= \frac{x^2 + y^2 - L_1^2 - L_2^2}{2L_1L_2} \\ \sin(q_2) &= \pm\sqrt{(1 - \cos^2(q_2)} \end{aligned} \tag{2.4}$$

In this kind of system there are two solutions for any configuration. But in this case the design of the arms have a well-defined work space, it is possible to choose the solution with the $\sin(q_2)$ positive for the left arm, and the solution with the $\sin(q_2)$ negative for the right arm. So we have:

$$\begin{aligned} \sin(q_1) &= \frac{y(L_2 \cos(q_2) + L_1) - L_2 x \sin(q_2)}{(L_1 + L_2 \cos(q_2))^2 + L_2^2 \sin^2(q_2)} \\ \cos(q_1) &= \frac{x + L_2 \sin(q_1)\sin(q_2)}{L_2 \cos(q_2) + L_1} \end{aligned} \tag{2.5}$$

Applying the inverse trigonometric function we get the values of the angles q_1 and q_2. The three arms have the same reference, so it is necessary to apply an off-set on the *x*- and *y*-axes for each arm to have the same origin. In addition it is necessary to introduce a supplementary *y* off-set for each arm because the picking points of the fingers are placed at arm ends as shown in Fig. 2.10c.

Grasping Picking Module

The fabric items must be lifted without damaging the fabric surface. Vacuum is used to generate the holding force and the design is for high air flow in order to cope with fabric porosity (Tsourveloudis 1999). In each grasping module vacuum is generated by means of an embedded microturbine (Carca et al. 2008). With the design adopted the average value of grasping force is 2 N. The tip end of the grasping unit comprises a net to prevent fabric suction inside the unit and needles to limit lateral movements of the fabric item.

2.3.4.3 Control System

The sequence and the management of the tasks in charge of the upper level control are implemented in C language on a commercial PC interacting with the grasping device controller. The grasping device low-level control is resident on a commercial control card. The adopted program language C based is easy to use and allows a full interface with the other devices connected with it through the TCP/IP communication network and Telnet-like messages.

The grasping device control card manages the micro-stepper motors for arms movements; the electro-pneumatic valves for the control of the finger lift, for the docking operation, for the SMA springs cooling system; the relays for the microturbine brushless motors and for SMA spring opening; the grasping device internal sensors and proximities for arm re-set.

The pneumatic circuit of the grasping device interacts with the pieces of fabric in the process and with the re-configurable hanger. Its functions are critical for the process of manipulation; they are: releasing of the joints of the re-configurable hanger, taking the fabric from the cutting table, blocking the re-configurable hanger, control the air flow to cool the SMA springs.

The service robot adopted is of type KUKA KR 16 (Fig. 2.11). This robot has a payload of 16 kg and repeatability < ±0.1 mm.

As for the grasping device the control system uses TCP/IP communication but in this case with an XML protocol allowing easy sharing of structured data across different information systems, particularly via the Internet, for both documents and serialised data.

To support the XML protocol the controller box of the robot was upgraded in the software and in the hardware with a 3Com real-time communication card.

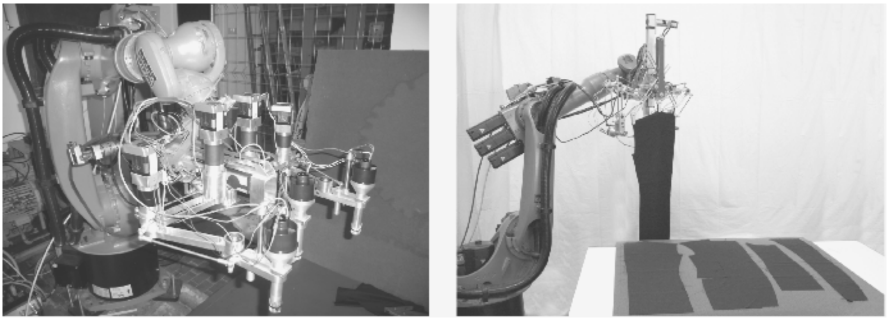


Fig. 2.11 The grasping device prototype

For security purposes a reference number, this is different for every cycle, is assigned to the tags of the messages received and sent. In that way there is no possibility that the robot is executing tasks of a past cycle and the robot is always aware of the ongoing time.

2.3.5 Conclusions

One of the still open, difficult to solve problems in garment manufacturing, is the handling of soft and limp natural or synthetic materials that can be porous or not and, usually, in the considered case of mass customised production are single-ply cut so the grasp and handling operations are made difficult by the variability of the shapes, sizes, material composition, thickness and stiffness. This kind of problem addressed the adoption of choice of multi-point picking technology and modular architectures inducing the authors to conceive an innovative grasping system and device architectures. Extensive use of virtual prototyping and testing has been a key factor towards straight and effective design with very low time-to-prototype.

2.4 Garment Manufacturing Plant Design and Concepts

Rezia Molfino, Matteo Zoppi, Roberto Montorsi

Abstract The aim of this section is to present concepts and methodologies to design effective and efficient manufacturing solutions pursuing the main industry success drivers of improving productivity, cost reduction and fast response to market. Furthermore, the system has to cope with the needs of the mass-customisation scenario overcoming the limitations that have so far prevented the automation of the garment assembly, through a comprehensive and general ('holistic') re-design of the garment manufacturing process, properly exploiting flexible auto-

mation and robotic technologies. High flexibility, self-adaptation, intelligent automation characteristics will address all the manufacturing resources and, wherever possible, robotic devices and mechatronic systems will be adopted to perform and/or to cooperate with human workers in primary (cutting, assembly …) and secondary (transport, positioning …) manufacturing tasks**.** LEAPFROG proposes new concept manufacturing cells and plants that integrate cells as independent modules together with related resources aiming at improving the flexibility and enhancing the versatility of the garment industry.

2.4.1 Mass Customisation and Garment Industry

The garment industry is increasingly involved in the application of mass customisation (Piller 2007). The reason behind this development can be seen in the fact that clothing offers the potential for addressing all three possible dimensions of customisation: fit (shape, measurements, size), functionality (features, taste, forms) and aesthetic design (fashion). Products that require the matching of different physical dimensions or functional requirements often engender a higher price premium than products that are customised just by the possibility of changing colours or design patterns. Garments are products that must, first of all, exactly fit the user's measurements. Additionally, customer involvement in the aesthetic design and the adaptation of functional requirements are further means of increasing the value of a product and its user's satisfaction.

Thus, customisation in this industry offers a good opportunity to counterbalance additional cost in manufacturing by the consumer's willingness to pay a higher price. Customisation is also favoured by more and more suppliers due to the steadily growing pace of change in fashion cycles, high forecasting problems, and multichannel distribution systems. However, the change has just begun in the fashion industry. Despite various approaches, like fast-response supply chain systems, the use of digital models in product design, or manufacturing robots substituting or assisting the traditional human labour, the apparel sector is still dominated by traditional mass (variant) production systems. Thus, making this industry more customer-centric is both a great challenge and an immense opportunity (Qin 2008).

The trend towards mass customisation and personal production leads to a fundamental revision of material flows and of the factory structures. Future factories have to be able to adjust themselves very rapidly to the customer's requirements. This requires short response time and a very high flexibility in structures and processes (Kincade 1995). New automation concepts are needed. Indeed, we are here interested in the manufacturing phase, in particular in the features of the manufacturing system that may best fit the new requirements.

Changing manufacturing environments characterised by aggressive competition on a global scale and rapid changes in process technology requires the creation of production systems that are themselves easily upgradable and into which new technologies and new functions can be readily integrated.

The manufacturing systems used for this new approach must be able to convert quickly to the production of new models, able to adjust capacity quickly, and able to integrate technology and to produce an increased variety of products in unpredictable quantities (Michelini 2001).

Hereafter, the major manufacturing paradigms and their main economic objectives are summarised.

Mass-production systems (Lin 1994) were focused on the reduction of product cost. Lean manufacturing places emphasis on continuous improvement in product quality while decreasing product costs. Flexible manufacturing systems make possible the manufacture of a variety of products (flexibility) on the same system (Buchanam 1995). While this is an important objective, these systems have met with limited success. For instance, flexible manufacturing systems developed in the last two decades (Byrne 1995): (i) are expensive, since in many cases they include more functions than needed, (ii) utilise inadequate system software, since developing user-specified software is extremely expensive, (iii) are not highly reliable, and (iv) are subject to obsolescence due to advances in technology and their fixed system software/hardware. The high risk of an expensive flexible production system becoming obsolete is one of manufacturers' most troubling problems. Because advances in computers, information, processing, controls, sensors, high-speed motors, linear drives, and materials sometimes occur in cycles as short as six months, today's most efficient production system can become inefficient after a short time. Further, the current customer-driven market and increased awareness of environmental issues lead to the ever-quicker introduction of new products. But adaptation of existing production systems to new products is slow and the launching of new systems can take a long time (up to two years for a machining system).

To address these limitations, new manufacturing systems technology must meet the following objectives, which go beyond the objectives of mass, lean, and flexible manufacturing:

- rapid upgrading and quick integration of new process technology and new functionality into existing systems;
- reduction of lead time (including ramp-up time) for launching new manufacturing systems and re-configuring existing systems.

This new type of manufacturing system will allow flexibility not only in producing a variety of parts, but also in changing the system itself. Such a system will be created using basic process modules – hardware and software – that will be rearranged quickly and reliably. These systems will not run the risk of becoming obsolete, because they will enable the rapid changing of system components and the rapid addition of application-specific software modules. This system will be open-ended, so that it can: (i) be continuously improved by integrating new technology, and (ii) be rapidly reconfigured to accommodate future products and changes in product demand rather than scrapped and replaced.

The resources of the new generation of manufacturing processes will develop along these characteristics:

- improved flexibility up to the target of eliminating every setup in changing from a style to other and eliminating all the tooling specifically needed for each given model;
- enhanced versatility, meaning by that the possibility of executing with a single resource and by using the appropriate end-effectors, more than a single operation, thus replacing, in the manufacturing cycle, many resources at the same time;
- self-adaptation, in order to be able to respond dynamically to changes in style and size and to automatically adapt to possible unexpected events of the real world such as a part that is not precisely positioned or badly assembled. This capability will make the process more autonomous and intelligent, able to react to sudden changes in the production and to unexpected events;
- high level of automation at every stage of the process to guarantee parts traceability and process visibility, the quality standardisation of the products, the removal of human errors and the reduction of manufacturing costs.

2.4.2 Garment Manufacturing Plant: System Hypotheses and Concepts

In clothing production the transformation of the fabric into a garment involves resources that directly modify the material and resources that are needed but do not add value to the product. We indicate as primary the first category and secondary the second one.

Analysing the traditional process flow, weak points are singled out in the sewing phases where the components of the same garment follow different paths to make subassemblies before being joined together, requiring a great effort in logistics and wide use of secondary resources. This work flow is really not suitable for mass-customised production, is labour intensive, difficult to monitor and subject to errors.

In the past decades, automation and digital design integration helped to innovate the cutting process but the following primary and secondary processes are very hard to automate because the fabric handling is an extremely difficult problem to solve.

One of the key objectives of the LEAPFROG project is the automation of garment assembly by means of innovative fast and highly reconfigurable robotic resources (multi-point gripper, adjustable 3D mould, robotic sewing machine) with as yet unseen dexterity, cooperation ability and robustness in handling and working with limp materials (fabric cut parts or semi-finished garments. To this aim the garment manufacturing system is re-engineered rethinking and radically redesigning the overall process and integrating new resources. New auxiliary processes dedicated to special treatments of the fabric, purposely studied, may be introduced in order to facilitate the primary (cutting) and secondary (grasping) processes.

2.4.2.1 The Modular Layout of the Manufacturing Plant

The reference process includes three main manufacturing sections: cutting, joining and finishing. In order to facilitate the process automation a modular approach is adopted: so robotised cells for the three recalled sections are defined and each section can be realised introducing a given number of cells as production needs require. At the limit one robotised cell per kind may concur to a lean manufacturing plant or can be integrated with the aim of demonstration of the feasibility of the new technologies adopted. Companies, convinced by flexible automation, may extend their manufacturing plants adding new robotised cells or substituting the old ones. The modularity allows an easy reconfiguration of the plant through the hardware and software integration (Acaccia 1996). Modularity facilitates the introduction of new technologies into small and medium-sized garment manufacturing enterprises that can help further specialising their processes and can improve their capability of collaborating in production networks.

2.4.2.2 Robotised Cutting Cell

In our case of the production of mass-customised high-quality garments (Acaccia 2001), this cell includes a traditional single-ply cutting table served by a robot equipped with a grasping device able to pick a cut part from the table, to transfer it to a hanger and to deliver the hanger to a transport system for routing to the following operative sections according to the work cycle of the garment to which the cut part belongs. The same philosophy is applied to multi-layer cutting (low or high ply cutters), in this case the grasping device is able to pick the whole pile of cut parts that will be suitably delivered to the transport system.

Precision points on the singularised cut parts, needed for the reference to the joining operations, are given from the CAD nesting station and are kept known and memorised up to the delivery to the joining section. For a specific type of formal men’s wear (the jacket of a suit), considered as reference product in the project, three reference precision points are required. They are selected so that the part grasped by picking it exactly through these points, while vertically hung, is kept flat and without wrinkles with the help of gravity.

Several robotised cutting cells can work in parallel in a garment-manufacturing plant.

2.4.2.3 Joining Cell (Sewing, Welding, etc.)

A joining cell is a cell that receives cut parts and/or semi-joined items belonging to the same garment and assembles them into a semi-finished or finished product. Different joining-cell typologies are considered: referring either to different joining processes, like sewing, laser welding, bonding either to the parts to be joined, e.g. jacket torso, sleeves, collar pockets or to the level of automation, e.g. human served, fully robotised, human robot assisted. These cells can work in series and in parallel.

A breakthrough robotised sewing-cell concept is proposed in LEAPFROG for flexible automation of garment manufacturing, see Sect. 2.4.1.1. This cell includes an adjustable 3D mould that can adjust to the style, drop and size of the garment on the fly, and is used as an active support for cut parts to be sewn in 3D. A special mechatronic device is used to load the cut parts, delivered from the transport system, referenced by the precision points on the hanger, on the mould. A full mobility robot equipped with a robotic sewing machine is in charge of executing the 3D sewing trajectories to join the parts kept positioned on the mould, see Sect. 2.4.1.5.

2.4.2.4 Finishing Cell

Finishing cells are devoted to specific finishing tasks like ironing, applying chemical finishes to selected areas, washing and drying, automated garment inspection, or the application of tags and labels in order to achieve consistent reproduction of desired chemical or mechanical finishes on individual garments. Different levels of automation characterise the cell composition, layout and working. Many finishing tasks can be very inconvenient (monotonous, strenuous or even hazardous) for humans and at least some level of automation has to be introduced. Robotised finishing cells may include: adaptable fixtures adapting to the garment and supporting it fully extended in three-dimensional form during the finishing operations; a robot able to drive and manipulate fully automated finishing tools like irons, steaming and spraying devices, inspection systems, labellers, etc.

2.4.3 The New Material Transport System

In the modular vision of the garment-production process the material-transport system plays the important role of interfacing and servicing all the manufacturing cells. In fact, each cell is thought of and realised as an independent autonomous holon endowed with its own control system driving the local manufacturing operations whose interfaces are allowed only to and from the transport system, as represented in Fig. 2.12. Further the transport system is used not only to trans-

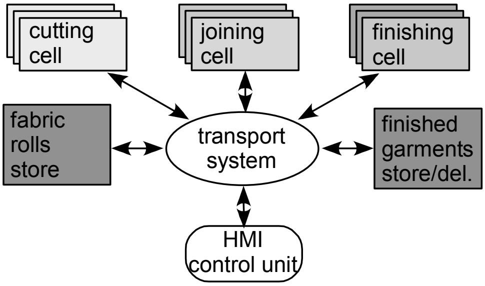


Fig. 2.12 Transport-system interfaces

port parts, semi-finished and finished garments, but also for their temporary storing inside the plant.

Different kinds of transport system can be used. The main choice is between continuous versus discrete.

Discrete System Moving Singular Hanging Parts

A discrete system moving single parts or garment assemblies is preferred because single items can circulate and reach their own destination without involving other items that will generate selection processes and potential errors or confusion. Taking into account the characteristics of the garment parts, subassemblies and assemblies the natural hanging position offers the advantages of: less footprint per item, item safely unfolded, transfer avoiding wrinkles, easy performance of some specific tasks without the need of item unloading (quality check, label affixing etc.). Each hanger is driven by a trolley moving on an overhead rail: different kinds of hangers are used for single cut parts and for semi-finished garments. The trolleys are powered: they move towards the destination programmed by the plant supervisor but they need to stop at any decision point for checking the actual status of the resources and for receiving data and updating their paths.

2.4.3.1 Use of Bypasses for Enhanced Flexibility

Working in between mass and one-of-a-kind production, comparatively inexpensive layouts can be worked out resorting to bypasses to add on-process flexibility dealing with material delivery flows and with unexpected occurrences (Acaccia 1996).

The routings of garment items is not following a pre-defined sequence of positions but can be suitably addressed on the basis of the actual plant status knowledge through bypasses. Branched transport layouts offer the possibility to chose alternative routes with the aim of balancing the plant-resources utilisation and to lower the throughput, by skipping overloaded, failed or in maintenance cells and avoiding the generation of queues and bottlenecks.

In Fig. 2.13 some plant layouts using bypasses are proposed.

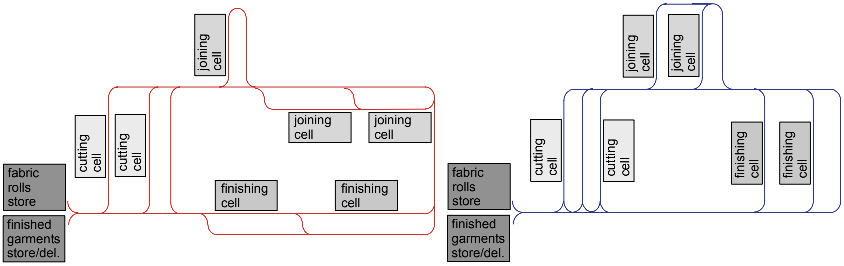


Fig. 2.13 Typical plan layouts with bypasses

Use of RFID for Traceability Functions

In order to provide flexible routing to improve the quality maintaining production throughput the usage of non-invasive embedded identification techniques is recommended (Mousavi 2005). The objective is to ensure automatic, continuous, error-free parts identification that would not interfere with normal production activities all along the manufacturing process. Radio-frequency identification (RFID) technology satisfies non-collision criteria and the integration of the system with the hardware and software system (Billo 1998). The proposed use of RFID represents a step forward towards intelligent garment manufacturing automation and the adopted solution is exploitable in other manufacturing sectors to provide to manufacturers and plant managers the knowledge of the single items status also in case of control-system shut down.

Each hanger embeds an RFID tag that identifies, besides the hanger status, the features and manufacturing status of the transported item.

The basic RFID information used by the plant control system are the hanger-identification code, actual status and statistic summary; the identification codes of the transported item and the garment/ production order to which it belongs, the next operation of the production cycle and all the information useful to perform the task successfully (sewing thread kind and colour, sewing type and path in case of sewing operation; ironing support fixture code, vapour temperature and iron path in case of ironing operation). All this information can be used as a reminder for the expert human operator or as a useful precious help for a lower-skilled operator. In any case at each manual cell the operator, after having finished the task, has to update the tag info.

2.4.4 Control Architecture

The control system of the proposed multi-cell plant is structured on two main levels: at the lower level the control is distributed on the single cells that behave as separate units whose dynamics evolve in parallel, each one referring to the upper-level control signals received through suitable interfaces. At the upper level the supervisor drives the transport system and pilots the plant activities via the communication network.

The robotised cells operate autonomously driven by their own control systems which will be activated by suitable signals from the plant inbound logistics. The human-assisted cells are driven by the operator who acts on the basis of signals received from the plant inbound logistics.

The transport control and routing activities scheduling is based on simple rules that are examined and run every time a transport unit (trolley) reaches a decision point. The decision points are points physically located on the transport rails where the control has to select the route or to change/update the status of the carried item. The main decision points are points interfacing the transport system with cells and switching points at bypasses or crossings.

2.4.4.1 Communication

The above-described architecture implies the need to adequately make the cells communicate among them and each cell with the RFID read/write devices, if present. Ethernet wire communication will be employed among the various ground units. Wireless communication will be employed where required, for instance to communicate with the trolleys. These wireless communications will use either WiFi or ZigBee techniques.

The WiFi technique permits higher transmission rate but it is less robust. The ZigBee technique is characterised by lower communication rate, lower range but it is more robust and permits the creation of wide communication systems thanks to the capacity of the ZigBee cells to transfer messages from one cell to the other.

Communication can be, for instance, TCP/IP. It is of great importance to use protocols whose contents can be easily implemented and where new cells can be easily added.

2.4.5 Example Application

With reference to the plant layout shown in Fig. 2.14 the logics at the main decision points are presented.

Logics concerning switching points at bypasses such as the ones introduced to skip the cut table unloading and robotised sewing cells are very similar.

Logics schemata concerning the robot-assisted manufacturing cells are similar but governing rules differ for different cell typology; the same applies for human-assisted cells.

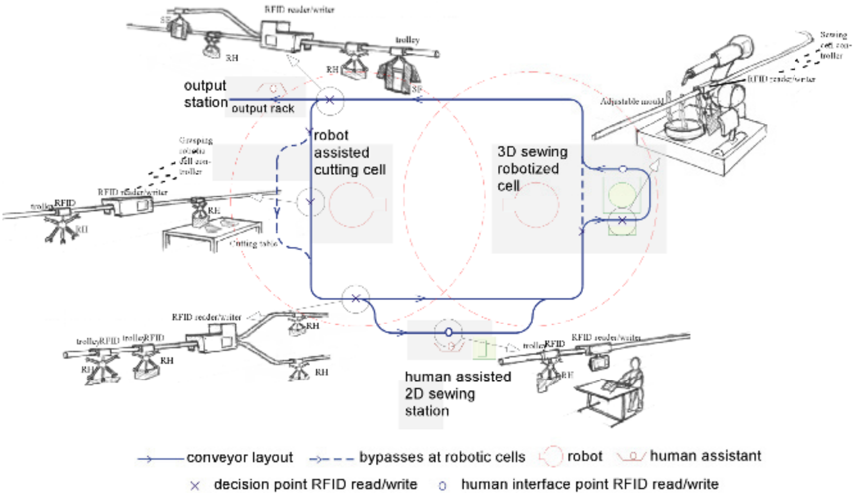


Fig. 2.14 Simple reference layout showing decision points

2.4.5.1 Robot-Assisted Cutting Cell

The RFID reader identifies the hanger kind and status to know if it is possible to start a cutting cell unloading cycle. In the positive case, the cycle starts and a part is loaded on the hanger; the RFID writer updates to 'loaded' the status of the hanger and initialises the RFID code and status with all the manufacturing info. When the loading cycle ends the loaded hanger is forwarded to the next decision point.

If the RFID reads from the hanger tag a different kind and status it is directly forwarded to the next decision point.

2.4.5.2 Robotic 3D Sewing Cell

If the RFID reader recognises the item on the trolley as a part to be assembled within the cell, it is stopped at the cell-interfacing point, in the other case, it is forwarded directly to the next decision point.

In the positive case a trolley unloading cycle is started; the RFID writer sets to 'unloaded' the 'hanger status' and removes from the RFID all the information related to the unloaded part. When the loading cycle ends the unloaded hanger is forwarded to the next decision point.

When the robotic sewing cell, after having received all the parts to assemble finishes the sewing operations, it calls for assistance and waits until a suitable hanger/trolley is available for loading it. After having finished this operation, the RFID status is updated, the hanger is loaded on the rail and is then forwarded to the next decision point.

Human-Assisted 2D Sewing Cell

At this interface point the RFID manages the interface with the human assistant by acoustic or visual warning and displays all the information useful to perform the work.

The assistant, after having finished, updates, through the HMI the info on the RFID and loads the hanger on the rail; the hanger is then forwarded to the next decision point.

Switching Point at Cell Bypass

On the basis of the RFID information related to the hanger and loaded part, the hanger is forwarded towards one of the branches of the bypass. The decision is taken by running the rules associated to the specific bypass.

Plant Output Bypass

This is a special bypass where it is decided if the hanger/item has to be output from the plant or has to be recirculated on the cell rail waiting for further operations.

2.4.6 Conclusions

This section has introduced new concepts for garment-manufacturing plant design. The competition between clothing companies resorts to the process-added value of actually sold apparel, rather than the production of large quantities of products followed by a search for buyers involving significant communication and advertising cost or low-price promotions. Customised premium clothing is a potentially high added value but also challenging product category, as clients require personalised quality combined with quick and reliable service. The section suggests looking to the integrated manufacturing approach with integrated intelligent transport systems as a suitable production concept. The process description is based on a modular layout, to separate the influencing effect of quantities and to be able to investigate details while preserving the overall view of the manufacturing process.

One should emphasise the fact that today the clothing industry is based on labour-intensive production systems and extensively resorts to the on-line operator's versatility to modify production, while the process progresses. This possibly hinders the benefit of intelligent manufacturing, which is based on a concurrent material and information flows to adapt the material dispatching service at the execution range through real-time supervisors.

The example discussion shows the feasibility of lean flexible automation in garment production. However, the benefits depend on a large number of cross-related facts and actual implementations. The LEAPFROG pilot plant at the company Robox will demonstrate the potential benefits and efficiency gains of the proposed solution in which the shop logistic service for the material dispatching and for items traceability is ruled by a decision logic incorporating on-process information by plausibility reasoning.

2.5 From CAD to Manufacturing – Automated Robot Programming

Claus Peter Eberhardt, Franz Engel

Abstract Robotic systems are basically used to increase productivity and quality of manufacturing processes by means of flexible automation. Thus, in the LEAPFROG project, robotics technology is regarded as a suitable instrument for improving the efficiency and flexibility of garment manufacturing in Europe. Robotic systems can be used in several partial processes in garment manufacturing. One of the most meaningful processes is the actual sewing of garments. There are currently a few automated and robot-guided applications for sewing. These applications require 'teach-in' of the garment's seam (sewing path). 'Teach-in' means manually positioning the robot at several auxiliary points on the seam/path and saving the position of the axes at these points. In this way, the robot can

subsequently be moved using the coordinates of these points during the automated process. 'Teach-in' entails high personnel and qualification costs and leads to long changeover times for teaching new products. This chapter describes a new method for the automatic off-line creation of robot programs 'at the push of a button'. The executable robot program is basically created by combining the CAD (computer-aided design) data of the garments (seam, sewing path) with template robot programs. The program is tested in a simulation environment to check functions, e.g. to test the reachability of points on the path or to detect collisions. If necessary, the program can be modified in the simulation environment. Following successful 'virtual' testing, the executable robot program can be exported and transferred to the robot controller in the production system. In this way, (new) products can be produced in 'batch size 1' with all the quality associated with automation.

2.5.1 Introduction

Garment manufacturing is characterised by a high level of manual operations. For this reason, production is increasingly being relocated to low-wage countries. In Western European countries, production is increasingly being confined to custom-tailored garments for the higher-price segment.

One way of safeguarding domestic production is to expand market segments that favour local production. Reasons for local production close to the market include the necessity for short delivery times or short information paths. These requirements are typical, for example, in prototype manufacture, where a wide range of variants is produced in small series. Another example is the widely discussed area of mass customisation, in which customer-specific goods are 'mass-produced'. Within the LEAPFROG project, automation solutions have been put together for efficient, robot-based manufacture of high-quality garments for these market segments.

One particular challenge in automated garment manufacture is the joining (sewing) of the individual pieces of fabric. In order to sew these flat, flexible pieces of fabric together to form a three-dimensional garment, they must be held, guided in three-dimensional space in combination with the sewing machine, and simultaneously sewn. To this day, due to this complexity, the sewing process is still mainly carried out manually. It is only the latest developments in materials handling and sewing technology, as described in the preceding chapters, that have opened up the possibility of robot-based automation.

In addition to the technological complexity, automated garment manufacture also entails programming and setup of the automation equipment prior to production of a series. In the case of series production with large numbers of variants, not to mention mass customisation, these tasks are extremely time-consuming. In extreme cases, e.g. batch size 1, every single item requires its own separate programming and setup. Furthermore, the preparatory work must be carried out by specially trained expert personnel. All of this means that this kind of production is simply not possible for economical reasons.

The solution, to reduce the cost of this preparatory work, is the automatic creation of executable robot sewing programs as the core element of an integrated process chain. For this purpose, the 'Visual Motion Planner' (VMP) software package was developed and implemented as a prototype within the LEAPFROG project.

2.5.2 Idea and Concept

The following example serves to illustrate the idea of an integrated process chain 'from CAD to robot program' with automatic program creation:

Today, a printer is expected to be able to transfer any print job – be it text or image – to a sheet of paper. No-one would expect to have to program the printer head or paper feed. Instead, a file is generated, e.g. by the word-processing program, that enables the printer to execute the print job.

Along the lines of this example, it is now possible to develop an integrated automatic process chain for garment manufacture, particularly for the sewing operations.

The designer designs the garment and provides it with sewing information, e.g. seam path or type. This is used to create a CAD file that is transferred to a program in which an executable robot program is automatically created. This robot program is transferred to the robot that then manufactures the garment. This is analogous to the way in which the printer executes the print job by transferring onto paper the information contained in the corresponding print file.

The sewing process is a path-controlled process along the seam. For this reason, before describing the implementation of the idea, a brief overview of the programming of robot-based, path-controlled processes will be given.

The origins of robotics are to be found in the automotive industry. Initially, the use of robots was restricted to spot welding. In spot welding, the path between the weld spots is of secondary importance. The main requirement is that the path must be collision-free. It was not until the mid-1980s that robots were first used for arc-welding applications. Here, the robot has to follow a defined path.

The initially demanding programming of robots and their paths was soon replaced by the 'teach-in' process. In the 'teach-in' process, the robot is moved to individual points on the path that is then saved. Between the points, the path is interpolated. Modern teach-in methods make the use of robots ever more conven-

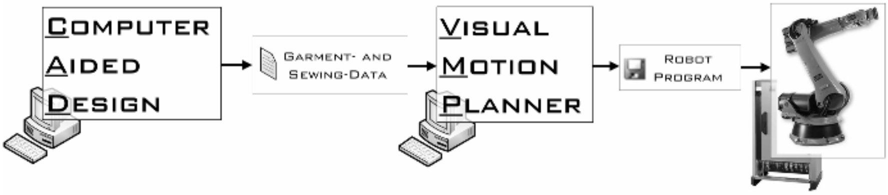


Fig. 2.15 Visual Motion Planner within the overall context

ient and intuitive. However, specialist personnel are still required and the teach-in process itself is extremely time-consuming. This results in lengthy downtime of the production system.

To avoid this downtime, off-line programming systems have been developed, making it possible for robot programs to be created and checked while the system is in operation. Today, there are powerful simulation packages available for carrying out the off-line programming, such as IGRIP, ROBCAD or KUKA Sim.

Although these simulation packages are becoming ever more powerful, the robot paths are still ‘taught’ manually, the coordination of robot and tool is still a time-consuming operation and process parameters are still entered by hand.

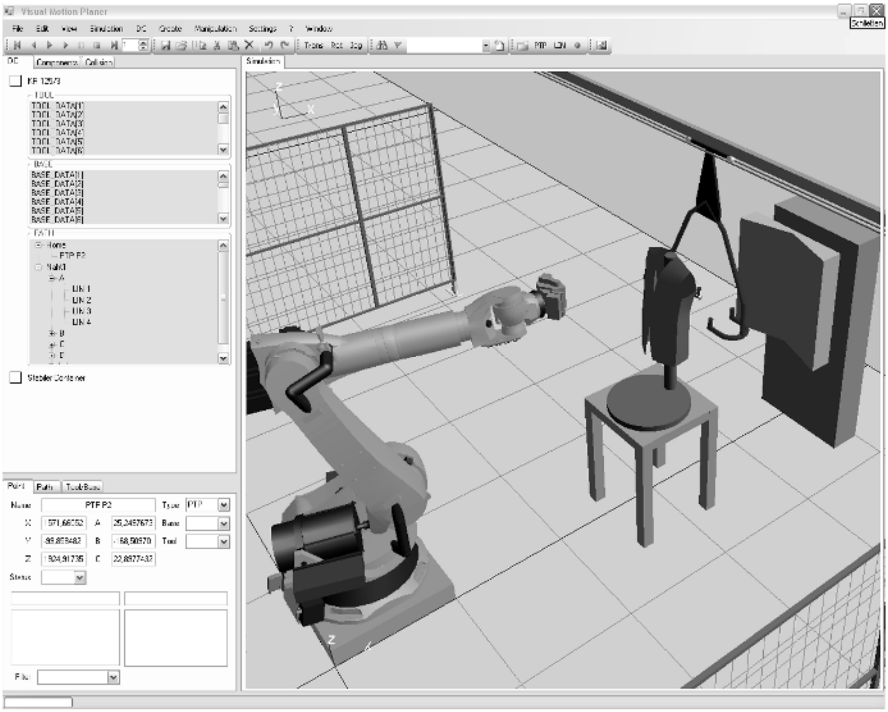
In order to dispense with the time-consuming teaching of the points on the path and the parameterisation and coordination of the robot and tool, and instead simply to take the required information directly from a CAD model, a new approach is being adopted. Thereby, the path is broken down into a large number of points. In addition to their spatial coordinates (x, y, z), these path points are also, if necessary, assigned the tool coordinates (orientation in space) as well as general and point-specific sewing parameters while still in the CAD system. Automatically executable robot programs are generated from this input information about the seam in conjunction with the CAD model of the sewing tool.

Even just a few years ago, this kind of approach to CAD-based off-line programming of complex paths, such as those that occur in the sewing of garments, would have been unthinkable from a practical point of view due to the large quantities of data to be processed. The robot controller would have been hopelessly overloaded as a result of the constant calculation of the path between the closely spaced points.

2.5.3 Visual Motion Planner

The Visual Motion Planner (VMP) was developed to take path data and parameters for robots directly from CAD systems and convert them directly into executable robot programs on the basis of templates. In addition to the sewing of garments, VMP is suitable for a wide range of path-related robotic applications, e.g. welding, adhesive bonding or milling. In the following sections, both the functional principle and the software architecture are thus described both in general terms and taking the specific example of sewing.

In today’s garment manufacture, the sewing process is preceded by the creation of 2D CAD models of the individual pieces of fabric from the designer’s draft. In the future, these are to be combined in 3D systems (garment simulation or CAD systems, see Chap. 4) to form a three-dimensional garment with defined seams. The definition of the seams can consist of parameters such as the seam type, stitching depth or stitch width in addition to the seam points.



Name PTP P2
Type PTP
X 1571,66052
Y -99,853482
Z 1504,91735
A 25,2457673
B -168,50970
C 22,8977432

Fig. 2.16 Visual Motion Planner – graphical user interface

The defined three-dimensional seam is then transferred to VMP. In VMP, the sewing process in the robotic cell with tool (sewing head) and workpiece carrier (mould) can be simulated. The seam is executed, the robot is told how the seam points are to be linked. Any collisions or unreachable points are detected. If required, the imported seam points and seam parameters or tool data can be displayed and manipulated. An operable robot program is then generated ‘at the push of a button’. Basic programs in the form of templates are available for this purpose. The robot program is then transferred to the robot controller.

The user interface of VMP is based on the Windows standard, thus enabling simple operator control of the software. Integration of the KUKA Sim robot simulation package ensures that all commonly used functions of robot simulation systems can be used.

In order to allow VMP to be used for as wide a range of path-controlled processes as possible, both the input format, with path points and process parameters, and the output structure, in the form of basic robot programs, can be simply and flexibly adapted to the requirements of the specific process. The flexibility of VMP derives from the fact that the VMP kernel is based on an interface structure that allows the easy addition of function blocks in the form of plug-ins. The interfaces are subdivided into interfaces for integrating plug-ins

- for importing various formats;
- For manipulating points and parameters;
- for exporting adapted robot programs.

The implementation of VMP as a C#-based software package ensures the simple integration of plug-ins offering a wide range of different functions.

For the sewing application, the first import plug-ins for widespread import formats have been developed and implemented for VMP. These are plug-ins for the XML-based COLLADA format and plug-ins for loading Excel and CSV files.

There are currently two manipulation plug-ins available to the user for editing points. The most important plug-in is undoubtedly one that allows the three required tool coordinates (spatial orientations) to be added to the 3D point coordinates where it is not possible to take the tool coordinates directly from the CAD model (‘from 3D to 6D coordinates’). A second manipulation plug-in can be used to homogenise the distance between points. A constant distance between the path points allows a reduction of the subsequent processing time required for the robot programs in the controller, thus stabilising the sewing process.

The export plug-ins are used to generate executable robot programs in VMP. An export plug-in integrates pre-structured robot programs into VMP and provides the functions for ‘filling’ these templates with path points and parameters. Templates that have been thus ‘filled’ are executable robot programs. Export plug-ins and templates are always application-specific, some even include system-specific features.

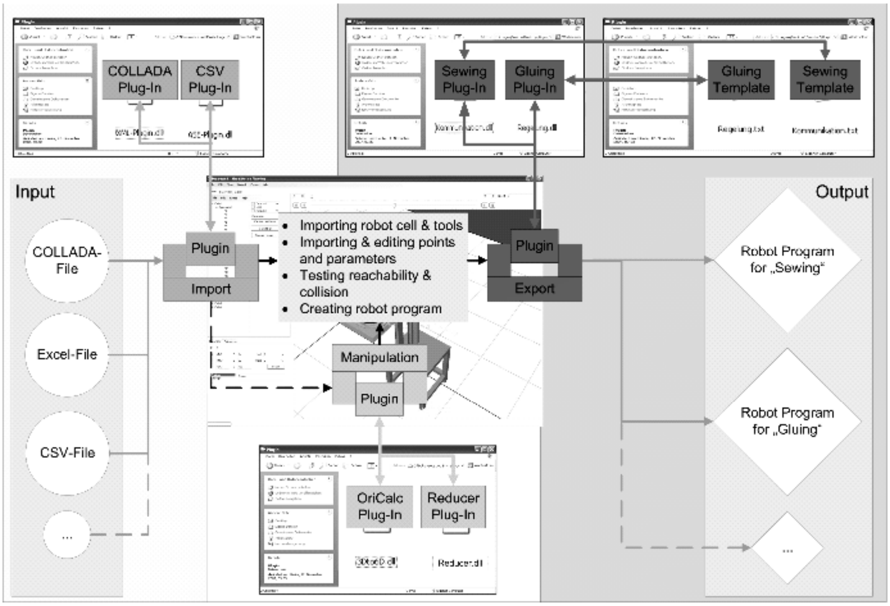


Fig. 2.17 Visual Motion Planner – architecture

The plug-in structure makes VMP a software package that can be simply and flexibly expanded and that can be used to generate executable robot programs directly from CAD data. Additionally, the existing integration of KUKA SIM means that the standard functions of this program can also be used.

2.5.4 Benefits

The initial situation described at the beginning of this section gave rise to the task, in the LEAPFROG project, of developing a software package for the efficient creation of robot programs for sewing garments.

The Visual Motion Planner (VMP) simulation package has succeeded in virtually automating robot programming for the sewing of garments. No specialist robot programming experience is required for operating the system. The time required for creating robot programs, teaching the robot path, setting the sewing parameters and testing the programs is reduced from several hours to a few minutes. Furthermore, VMP makes all commonly used functions of robot simulation systems available and can be run on commercially available PCs.

VMP thus enables the efficient application of robots for sewing garments in order to implement automation solutions for prototype manufacture or customer-specific garment production.

VMP is being developed further so that it can be used for more than ‘mere’ off-line programming. The focus here is on aspects such as process control in the case of path deviations or on-line process visualisation.

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Chapter 3
Innovative Textile Materials, Stiffening Procedures and Fabric-Joining Methods

3.1 Shape-Memory Textile Polymer Fibres

Yan Ji, Mark Schaerlaekens, Eugene M. Terentjev

Abstract The use of shape-memory polymers in textile application is relatively new, because the stringent requirements on mechanical strength and thermal stability of fibres have been so far hard to meet. This section reviews the current state-of-the-art, focusing on the key characteristics of the polymer materials required to produce textile-grade fibres, and the techniques of filament production. An extensive review of literature on this subject is presented, with the results of our own development of shape-memory polyurethane polymers and their fibres for textile applications.

3.1.1 Introduction

Shape-memory polymers (SMPs) are featured by their capability to change shapes in response to external stimuli. Compared with shape-memory alloys, SMPs have advantages in terms of cost, processability, and versatility of chemical composition. The majority of SMPs are thermally responsive elastomers, which are cross-linked by physical self-assembly or chemical bonds. Such cross-linked networks could be deformed from their original shape by an external force, when above its ‘switching transition temperature’ (T_{trans}). The T_{trans} is either a melting point of semi-crystalline polymer, or a glass-transition temperature. Upon cooling down to below T_{trans}, the material would retain this temporary shape even if the stress is removed due to internal constraints established in the material. This part of the process is called ‘programming’. As the temperature increases to above T_{trans}, the original shape would be restored due to the internal constraints removed

(Lendlein, 2002: 2034). In shape-memory alloys the corresponding T_{trans} is due to the martensitic phase transition (Otsuka, 1999: 511). Both classes of materials are in great contrast to liquid-crystalline elastomers (Tajbakhsh, 2001: 181), where the shape-memory effect originates from the coupling of orientational order and the material shape; in this case, no extra force is needed to deform the shape and this deformation is spontaneously reversible.

The ordinary SMPs have been comprehensively investigated in academia, and also attracted large interest from a wide spectrum of industry. The first marketable SMP product was polynorbornene, developed by Nippon Zeon in 1984, soon followed by shape-memory polyurethane introduced in 1988 by Mitsubishi. Many more companies have joined this market since then. CRG Industries, LLC, now produces thermoset styrene-based SMP under the trademark of Veriflex. Composite Technology Development Inc. (CTD) has developed reinforced SMPs with carbon or other fibre fillers. Bayer MaterialScience AG chose thermoplastic shape-memory polyurethanes. Early applications of SMPs were found in heat-shrinkable tubing, packaging materials, self-adjusting utensils, and so on, with an increasing attention focused on the biomedical field, as elegantly exemplified by Lendlein and Langer with the self-tightening knot (Lendlein, 2002: 1673). MnemoScience GmbH is fabricating self-tightening biodegradable thermoplastic sutures.

Recently, a new promising area in which SMPs are seeking a role is textiles (Hu, 2007). Even though some liquid-crystalline SMPs has been tested as textile fibres (Ahir, 2006: 556), the majority of SMPs used in textile are non-liquid-crystalline and actuated by temperature, only in one direction. There are two different ways to obtain shape-memory textile fibres. The first one is coating SMPs onto the surface of other common textile fibres such as cotton, to improve the properties of the fabric. That is to say, SMPs are used as finishing agent in textile and the shape-memory effect is transferred from SMPs to the fabric. The main purpose is to improve the water-vapour permeability (Cho, 2004: 2812; Jeong, 2000: 3009; Mondal, 2007: 282) or enhance the aesthetics of woven textiles (Chan, 2007: 290). The SMP coating on the fabric surface is important to reduce the residual stress within the fibres, thus helping to transfer the shape-memory effect to the fabric (Liem, 2007: 748).

Another way is to spin the SMPs into textile fibres directly (Ji, 2006: 1547; Meng, 2007: 2515). Presently this area is still in the initial state. Apart from the shape-memory effect, to obtain a proper textile fibre, the SMPs should combine appropriate mechanical properties (tensile strength, rigidity) and spinnablity, which is determined by the melting point, thermal stability and viscosity. This makes the majority of commercially available SMPs unsuitable for textile fibres. In addition to the basic fibre spinning, several post-treatments including drawing, heat-setting (Kaursoin, 2007: 2172) and steaming (Zhu, 2007: 969) were investigated to improve effects of the resulting yarn. Carbon nanotubes could be incorporated to enhance polyurethane fibres (Meng, 2007: 837; Meng, 2008: 314). This review is focused on efforts on these non-liquid-crystal SMPs in the development of shape-memory polymer textile fibres, both from the literature and from our results, especially in the chemistry and spinning process.

3.1.2 Chemistry of SMPs for Textile Fibres

A large number of polymers have been found possessing a shape-memory effect despite their totally different chemical compositions, such as polynorbornene, trans-polyisoprene, copolymers of styrene-butadiene, copolymers of polyethylene terephthalate–polyethylene oxide, cross-linked polystyrene and segmented polyurethane (Lendlein, 2002: 2034). So far, SMPs used in textile applications are mainly polyurethanes (PU), whose T_{trans} can be tailored by the control of chemical composition. Having served in the textile industry for more than two decades, polyurethane distinguishes itself by excellent mechanical properties, such as medium tensile strength and high elongation. Large-scale synthesis of PU is relatively easy and cost effective. PU shows high recovery strain in its shape-memory effect. The complex relationship between mechanical properties, shape memory and the chemical structure of PU has been examined in the literature, providing a selection of fundamental choices to satisfy the specific requirements of textile by varying structural parameters. For example, it was found that both T_g and T_m could be used as the switching temperature T_{trans}, which could be adjusted by changing the molecular weight of starting materials. The final recovery speed depends significantly on the density of physical cross-links and the length of PU flexible segments, which determines the level of network entanglements. Decreasing the cross-linking part (hydrogen-bonding rigid blocks of PU chains) increases the hysteresis in the shape memory. In some cases, the mechanical properties of PU could be improved by higher degree of crystallinity of the flexible block (Cho, 2004: 1343; Jeong, 2000: 1579; Kim, 2000: 2652; Lee, 2001: 6431; Li, 1997: 1511; Lin,1998: 1575; Ping, 2005: 587; Yang, 2003: 3251; Takahashi, 1996: 1061; Tobushi, 1996: 483).

The chemical structure of a generic polyurethane (PU) can be complex and diverse. Normally, it is formed through the step-growth polyaddition of diisocyanates with polyol and extended by diol or diamine. The synthesis could be two-step or single-shot. In the two-step method, pre-polymer is formed by the reaction of dissocyanate and polyol. Then, the diol or diamine as extender is added to connect the pre-polymer segments into the final high molecular weight polymer. In the 'one-shot' method, all the starting materials react simultaneously. A two-step or pre-polymerisation method is usually favoured in the preparation of shape-memory polyurethane (SMPU) because it results in a more uniform distribution of the size and properties (Cho, 2004: 2410). The two most commonly used diisocyanates for PU synthesis are toluene (TDI) and diphenylmethane diisocyanate (MDI). Polyols could also vary greatly, but usually are chosen from polyester or polyether polyols. Chain extenders are usually chosen from ethylene glycol, 1,4-butanediol (1,4-BDO or BDO), 1,6-hexanediol, cyclohexane dimethanol and analogous materials. The nature and ratio of dissocynates, extenders, and polyols is important since it has a dramatic effect both on the polymerisation reaction and the resulting physical properties of PU, including the shape-memory effect.

The shape-memory PU chain normally consists of alternating hard segment (formed by dissocyanate and extender molecular groups) and soft segment (formed by polyols). Hard segments of different chains bind to each other via hydrogen bonding and subsequent crystallisation, acting as physical cross-linking of the network of soft segment domains. Phase separation occurs between the non-polar soft segments, which have a relatively low melting or glass-transition temperature, and the rigid, polar, hard segments with a high melting point. It is generally accepted that the shape-memory effect originates from such phase separation (Cho, 2004: 2410). Shape retention depends on the interactions between the hard segments, while the shape recovery comes from the reversible phase transformation of soft segments, whose phase-transition temperature (T_g or T_m) determines the switching point T_{trans}. Therefore, the shape-memory effect can be tailored by varying the choice of starting materials and the polymerisation process.

Spinning of shape-memory textile fibres is still in its infancy. Only a few examples of shape-memory PUs were reported in the open literature. One is a commercially available PU from DiAPLEX (Tokyo), which is composed of polyethylene adipate, MDI, BDO, and bisphenol-A (Kaursoin, 2007: 2172). Similar chemical composition, but without bisphenol-A, was employed by Hu et al. to produce shape-memory PU fibres by wet-spinning (Ji, 2006: 1547). The polyethylene adipate that they used has a molecular weight of 600. PU was synthesised in two steps with dimethylformamide (DMF) as solvent. Hard segments content varied around 50–60%. Also, with MDI and BDO as hard segments, but replacing polyethylene adipate with poly(buthylene-adipate) (PBA) diols, Hu's group not only obtained shape-memory wet-spun polyurethane fibre with complete shape recoverability, but also illustrated the effect of steaming and hard segment content on the shape memory of fibres (Zhu, 2007: 969; Zhu, 2006: 1385). In order to enhance the mechanical strength of melt-spun fibres, carbon nanotubes were added to PU synthesised from PCL ($Mn = 4000$), MDI and BDO by two-step bulky polymerisation (Meng, 2007: 830). The reaction took place in a twin-screw extruder, resulting in PU with a Mn of 1.37×10^5. They also substituted MDI by isophorone disocyanate (IPDI) (Meng, 2008: 131). By two-step melt polymerisation, the obtained polyurethane has a Mn of 1.67×10^5 and is suitable for melt spinning.

Searching new candidates for shape-memory fibre spinning and optimising their associated synthesis procedure is essential for the development of better shape-memory textile fibres. Not many shape-memory polyurethanes reported are suitable for textiles, either because the mechanical strength is insufficient, or because shape recovery is not large enough for relevant applications. Molecular design of candidates for shape-memory textile requires a compromise between strength, elasticity and shape-memory effects. Thermostability is also a big problem for melt spinning. Examples include modifications of the hard and soft segments moieties, the segment length, the molecular weight of the soft segment, polymerisation procedures and so on. Aiming at new shape-memory fibres with high mechanical strength for robust textile weaving, we synthesised a shape-memory PU with good mechanical strength and spinnability. MDI and 1,6-hexanediol (1,6-HD) were chosen as the components of the hard segment, and the semi-crystalline PCL as soft segments. Flake-like 4,4'-diphenylmethane diisocyanate (MDI, Acros Co.) was melted at 60°C under vacuum and the MDI dimer precipitates were removed by vacuum filtration before use. DMF solvent was used after dehydration with a 4-Å molecular sieve for more than 2 days. PCL with a molecular weight of 10,000 was prepared by ring-opening polymerisation of ε-caprolactone at 130°C for 2 days with ethylene glycol as initiator and Sn(Oct)2 as catalyst. It was purified by precipitation in petroleum ether and dried at 60°C overnight before use. During synthesis, PCL was vacuum dehydrated at 90°C for 3 h and then the temperature was decreased to 70°C under nitrogen before 1,6-hexanediol and DMF were added, stirring the mixture for 5 min. A calculated amount MDI was added and the reaction under N_2 continued at 60°C for at least 12 h. The resulting mixture was cast on a glass plate. After the evaporation of DMF at room temperature, films were further dried at 80°C under vacuum for 24 h. The films were palletised and vacuum dried again at 80°C for melt spinning. Samples having different molecular weight were prepared by varying molar ratio NCO/OH, 1.05 for high molecular weight, while 1.0 for low molecular weight. Of the different solvents we used, DMF gave the higher molecular weight. The chemical structure is illustrated in Fig. 3.1. The average molecular weight was 80,000, as determined by GPC for the high molecular weight PU; Mn was 30,000 for the low molecular weight PU.

The PCL-PU obtained by this procedure has very good thermal and mechanical properties. As we can see from the DSC curve in Fig. 3.2, PCL-PU shows two thermal transitions during heating. One is about 49°C, which is the melting point of the PCL and corresponds to the switching temperature T_{trans}; the other is around 191°C, which is ascribed to the melting point of rigid segments, see Fig. 3.2. This upper melting temperature determines the lower bound for the melt-spinning conditions.

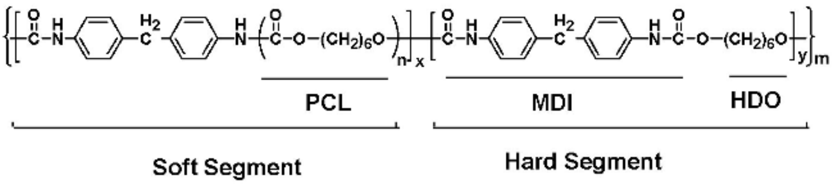


Fig. 3.1 Chemical structure of shape-memory PCL-polyurethane

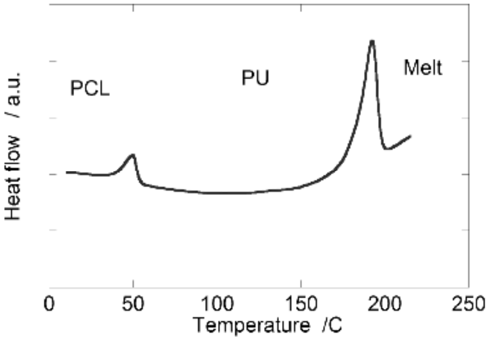


Fig. 3.2 DSC curve of PCL-PU (Mn=80,000), showing the widely separated melting points of the polyurethane and poly ε-caprolactone blocks. Below 191°C the PU blocks are H-bonded and crystallised, holding together the rubber-elastic network; below 49°C the PCL blocks are semi-crystalline as well

According to our experience and the reports from the literature, the following factors should be taken into consideration to design and synthesise shape-memory textile fibres.

1. **Proper melting point of the PU** It is well known that PU tends to chemically degrade near or above the melting temperature (Gupta, 2003: 169). For wet spinning, the melting point of PU is not a big issue, but high T_m of its hard segment prevents a lot of SMPUs from melt spinning, which is more convenient than wet-spinning. The melting point of PU relies on the hard segments and determines the temperature setting for melt spinning. Usually, the melt-spinning temperature is higher than the melting point of PU to get the best rheological response of the melt for fibre drawing. The melting point could be adjusted by the choice of hard-segment composition, that is, diisocynate or extender, which could reduce interchain interactions such as hydrogen bonding. However, the decrease of the melting point also means less interaction of hard segments, which may weaken the physical cross-linking and affect the corresponding mechanical properties. For example, we used to choose TDI instead of MDI as the hard segment. Similar to the result reported by Ping et al. (Ping, 2005: 587), the TDI-based polymer had a lower melting point; however, the mechanical strength was insufficient for fibre spinning over related MDI polyurethane containing the same soft segment. The magnitude of the shape-memory effect also suffers by using TDI. Our experiments show that changing the extender BDO to HDO leads to a decrease of T_m by about 30°C while maintaining the required mechanical strength of the product. Diamine was not as good as diol because urea-urethane groups have too high a melting temperature.
2. **Choice of soft segments** The shape-memory transition temperature depends on the T_g or T_m of soft segments. Generally, partial crystallisation of the soft segment (T_m) is preferred to the glass state (T_g) because the transition is sharper and the temperature at which the shape could recover is better specified. As regards the shape-memory effect, the T_m-type SMPU samples showed higher shape retention than those of T_g-type. Meanwhile, the soft domain has a great effect on the elasticity of the polyurethane. In terms of thermostability, polyester diol is better than polyether diol at the same melt spinning temperature. Because of the good shape retention and recovery of SMPU based on PCL, PCL-based-SMPU, especially those with MDI and BDO as hard segments, were extensively researched (Takahashi, 1996: 1061; Kim, 1996: 5781). Since shape fixation originates from the melting and crystallisation of soft segments, any factors related to crystallisation may influence the shape-memory effect. Depending on the molecular weight of PCL, the resulting block-copolymer PU materials could have their switching temperatures between 44 and 55°C. The degree of crystallinity of PCL segments increases with increasing molecular weight of PCL. In fact, it was found that PCL with a Mn lower than 2,000 could hardly provide a shape-memory effect because it is not easy to crystallise. Therefore, a relatively high molecular weight of PCL is necessary to obtain shape memory fibres. In our case, PCL with Mw of 10,000 was chosen to get better phase separation.

3. **Ratio of hard segment to soft segment** On the one hand, too much hard segment hampers the crystallisation of PCL and decreases the T_{trans}. On the other hand, the hard segment content must exceed a certain minimal level to be able to function as effective physical cross-linking, and the associated shape recovery. After studies varying the hard segment content, Li et al. found the optimum hard segment content to be 30–45 wt% for their PCL-MDI-BDO shape-memory PU; below 10 wt%, the hard segment could not offer the necessary cross-linking and mechanical strength (Li, 1997: 1511). In our experiments on the PCL-PU polymer with the structure illustrated in Fig. 3.1, 55 wt% still works well. This could be because we use MDI-HDO combination as hard segments. For the mechanical properties, the tensile strength was enhanced with the hard segment; however, the shape-memory elongation decreased with an increased amount of hard segment.
4. **Molecular weight of the PU chains** The spinnabilty is greatly dependent on the molecular weight of the whole PU because the chains have to be sufficiently entangled in the extruding melt in order to retain the fibre shape until the moment of physical cross-linking as the temperature drops. Low molecular weight results in low melt viscosity and, below the entanglement threshold no fibres could be formed on extrusion. However, the higher the molecular weight, the less the soft segment crystallises, leading to lower shape-recovery temperature. With increasing molecular weight, the shape retention decreased but the shape recovery may increase.
5. **Antioxidants** Like ordinary polyurethanes, the shape-memory PU degrades by oxidation, which could be initiated by heat or/and light. The degradation leads to changes in the molecular structure, as well as physical property deterioration. The shape-memory PU become yellowish after two months exposed in the air. A substantial decrease of mechanical strength was recorded for aged samples. To address this oxidation problem, 0.6% butylated hydroxytoluene was added to our shape-memory PU. It effectively prevented the PU from colouring and decomposing during the melt spinning.

In addition to the factors mentioned above, other polymerisation details affect the property of the PU as well. For example, reaction and curing temperature could change the molecular weight of the PU. To get shape-memory PU with proper mechanical strength, thermostability, and shape-memory effect, all those designing factors need to be tuned for optimal results.

3.1.3 Spinning of SMPU

In theory, SMPU fibres could be spun by different techniques, such as wet, dry, chemical and melt spinning. In the open literature, both wet and melt spinning methods were used. It is easy to understand that thermoplasticity is a basic requirement to get fibres from SMPUs by wet or melt spinning. In the spinning process, the polymer must be first converted into a viscous fluid state. Then, it is forced through the small holes of a spinneret to form continuous filaments. During the solidifying process, the filaments may be stretched to give them extra strength as a result of the shear-induced orientation of polymer chains.

Wet spinning is the oldest process. In this process, the viscous fluid is achieved by dissolving polymer in a suitable solvent. As the filaments emerge, they are precipitated from solution and solidify (Ji, 2006: 1547; Meng, 2007: 830).

As shown in Fig. 3.3, the chains of SMPU (e.g. made of polyethylene adipate glycol, MDI and BDO (Ji, 2006: 1547)) were dissolved in DMF first. After filtration and degassing, the solution was extruded. The spinneret contained thirty nozzles 0.08 mm diameter. In the coagulation bath, water was used to solidify the extruded filaments. A spinning speed of 6 m/min was achieved. After solidification, the filaments were rolled with a speed of at 10 m/min, rinsed with water, and dried in a hot chamber before they were wound up.

In the melt spinning, the viscous solution is achieved by melting the rigid segments of polyurethane. After extrusion, the filaments are directly solidified by cooling. Compared to wet spinning, melt processing does not use organic solvents, which makes the procedure cleaner and relatively simpler. Furthermore, melt spinning can be used to prepare fibres with different cross-sectional shapes, according to the design of the spinneret. But for this procedure, thermostability of the high molecular weight polymer is quite demanding because of the usually very high melting temperature. The polymer chains could be formed before melting and extrusion, or by *in-situ* polymerisation. One particular advantage of the melt-spinning process is the possibility to introduce fillers, e.g. carbon nanotubes or other additives, to improve fibre properties.

For comparison, both solution- and melt-spinning methods were used to spin the same materials into shape memory fibres (Meng, 2007: 1192). It was shown that in terms of tenacity, breaking strain, and shape-memory effect of the fibres, melt spinning is far more advantageous. The reason may lie in the more organised crystallisation during melt spinning under shear compared to the wet-spinning, which involves an additional significant volume-shrinking stage. We also carried

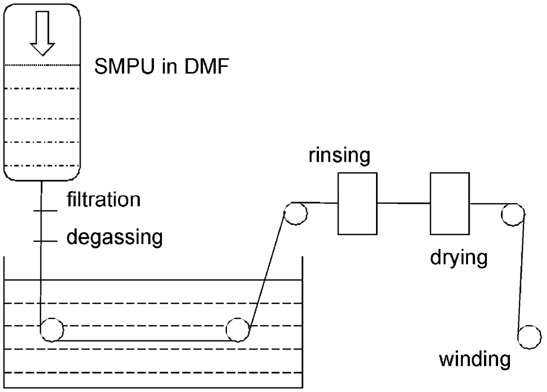


Fig. 3.3 Scheme of wet-spinning equipment

out melt-spinning of SMPU after the polymer illustrated in Fig. 3.1 was synthesised and purified by precipitation in methanol.

1. **Sample Preparation** Since the presence of moisture during high-temperature processing results in fast degradation of PU chains, moisture control during extrusion is extremely important. Processing sample material with high moisture content led to fast visible degradation (dark brown colour, severe loss in mechanical strength). Different drying procedures were evaluated (Maquire oven, vacuum oven) and optimised drying conditions were determined to be at 80°C for 30 h in vacuum. Antioxidant is necessary for sample preparation. This could be added to SMPU during the compounding stage. 0.6% of butylated hydroxytoluene was proved to be effective for our SMPU. Of course, other kinds of antioxidants that are commonly used for polyurethane could also be chosen. A single-screw lab-scale compounder was used to compound the grinded material. After drying, 0.6% butylated hydroxytoluene was manually added. The mixture was compounded at a temperature of 200°C into pellets.
2. **Spinning Process** Direct processing on the laboratory-scale device 'Plasticiser' was carried out. In the standard setup, the pellets of polymer material are fed into a single-screw extruder consisting of four heating zones for melting. Due to the geometry of the screw and barrel the pressure builds up in the extrusion zone (not controlled in this equipment), and the polymer is pressed through a multifilament (or monofilament/ tape/ film) die. A scheme of the 'Plasticiser' device is depicted in Fig. 3.4.

For testing of small quantities of material (about 5 g), the capillary of a melt-flow index (MFI) measuring device (Shenoy, 2003: 1) was used to replace the extruder and spinneret, which were used for larger quantities of polymer (about 100 g). The polymer was pre-heated in the capillary to go into melt state, and af-

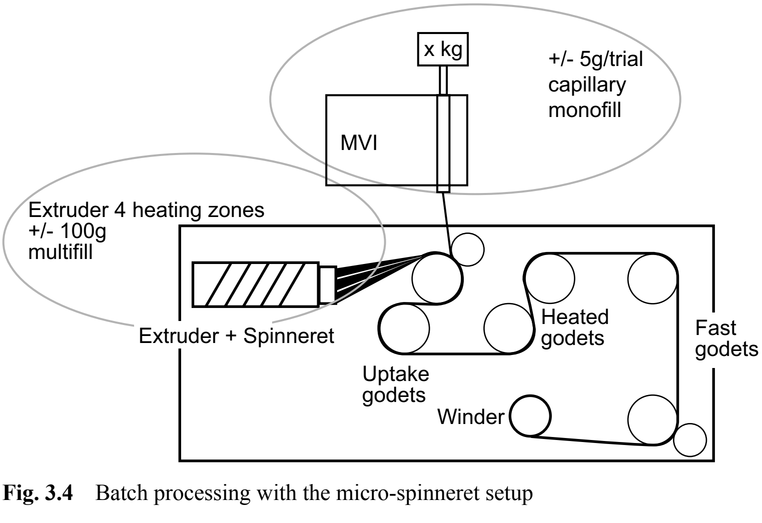


Fig. 3.4 Batch processing with the micro-spinneret setup

Table 3.1 Processing conditions of SMPU

Processing conditions	Preliminary Testing
Temperature	200°C
Die	1.8 mm
Weight MFI	2.16 kg
Take-up	3.7 m/min
Draw-roll	8.9 m/min
Winder	0.2 m/min

terwards pressed through a single die. Preliminary tests showed that the material could be processed with the following optimised settings, and resulted in a continuous monofilament with good mechanical characteristics. Settings of the monofilament drawing are given in Table 3.1.

3. **Fibre properties and influence of molecular weight** At the above spinning conditions, samples formed by different molecular weight PU behaved very differently. For example, samples with lower molecular weight (Mn = 30,000) and better shape-memory effect have not been viscous enough for winding as their melt flow index (MFI, defined as the mass of polymer in grams flowing in 10 min through a capillary at a prescribed pressure (Shenoy, 2003: 1)) is too high (see Table 3.2). In contrast, for the high molecular weight (Mn = 80,000) entangled melt, the MFI was low and the drawing was efficient; as a result – a bobbin of continuous monofilament could be prepared as shown in Fig. 3.5.

The resulting fibres showed very good mechanical characteristics and high shape-recovery ratio. The fibres prepared in such a condition had their tenacity at a peak of about 0.151 N/tex, and the strain at break of 147%. At ambient temperature, the modulus of SMPU fibre had a value of 0.1 N/tex. The SMPU fibre had a shape-recovery ratio more than 95% under thermal drawing and recovery cyclic tensile testing. Therefore, this kind of SMPU could be a promising material for the textile shape-memory fibres.

Table 3.2 MFI of SMPU with different dies

Die diameter	High Mn	Low Mn
1.8 mm	3.3	16
1.5 mm	2.5	12

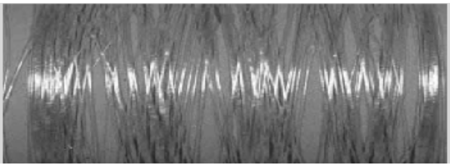


Fig. 3.5 Bobbin of SMPU with high molecular weight, from melt spinning

4. **Electrospinning** Electrospinning has been known as an alternative technique to produce thin polymer fibres since the 1930s. Currently, it is the only established technique to prepare continuous fibres with controlled diameters down to a few nanometers. Similar to the scheme used by Cha et al. (Cha, 2005: 460), depicted in Fig. 3.6, a typical electrospinning device consists of a high-voltage electric source with positive or negative polarity, an extruder pump and a conducting collector, which is usually held at ground potential. In bench-top laboratory conditions a syringe pump is frequently used as an extruder. Polymer, in solution or as a melt, is pumped through the syringe, forming a drop at the nedle tip. When a threshold voltage is applied, the drop becomes positively charged and thus electrostatically attracted to the collector. Due to high uniaxial electrostatic force, a jet of polymer extends from the needle tip towards the oppositely charged collector. During this process, the solvent evaporates, if used, or the melt cools, resulting in fine fibres formed and deposited on the collector. In recent years, electrospinning process has received increased attention due to its the growing importance in nanomaterials.

Typically, electrospun fibres are collected as a random non-woven mat. The mats have small pore size and high specific surface area. Such a feature could affect the transport process of water vapor and other gases, as well as anomalous surface tension leading to phenomena such as the lotus effect (self-cleaning surface) (Barthlott, 1997: 1). Lack of mechanical strength and challenge to obtain continuous yarns make typical electrospun fibres hardly fit for basic textile fabric preparation. However, electrospun non-wovens could be used in combination with conventional textiles to improve some performances of textiles, such as wind resistance, thermal insulation, vapor permeability, and so on (Lee, 2006: 3430). Electrospinning of PU has been examined for textile fabric in several papers (Lee, 2007: 696; Liu, 2006: 309; Park, 2007: 564). Shape memory PU with various hard-segment ratios were also electrospun from solution in the mixture of THF and DMF (Cha, 2005: 460). As with the conventionally spun fibres, it was found that the tensile strength increases with the increasing content of hard-segments. The shape recovery could be over 80% in this case.

To further explore the potential of our PCL-SMPU in textiles, we have carried out electrospinning of the PCL-PU polymers illustrated in Fig. 3.1. The effects of different process parameters, such as solution concentration, applied voltage, ex-

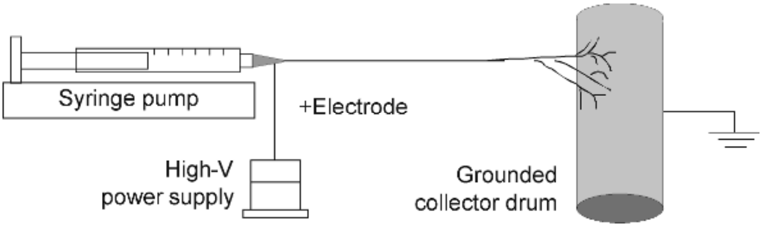


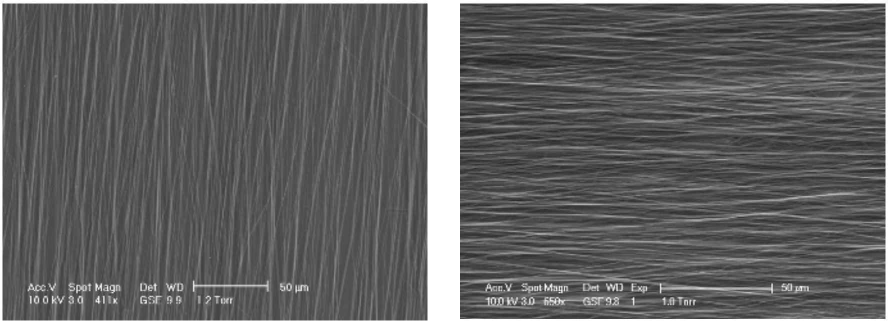
Fig. 3.6 Scheme of electrospinning apparatus

truder tip–collector distance, were systematically analyzed. PU solutions were prepared in HPLC grade DMF with concentrations of 10, 20, 30 and 40 wt%. The working distance to the collector varied in the range of 10–20 cm. Positive voltage applied to PU solutions was in the range of 8.5–12.5 kV. The solution infusion rates varied between 0.05 and 1.0 ml/h. All the electrospinning tests were carried out at room temperature. The morphology of the electrospun fibres was observed with an environmental scanning electron microscopy (ESEM) and optical microscopy. The fibre diameters of non-aligned fibres were measured from the optical micrograph using ImageJ software (Freeware version 1.31).

Fibre formation and morphology could be influenced by electrospinning parameters including solvent volatility, the applied voltage, the distance between the needle tip and the ground electrode (the working distance, WD), needle diameters, solution concentration. The ideal values of these parameters vary considerably for different polymer systems. In general, fibres become more uniform and have larger diameters with increasing concentration, because (as with wet-spinning) the entanglement of polymer chains at the drawing stage is the key. In our case, at fixed operating regimes (voltage = 12.5 kV, WD = 10 cm, infusion rate = 0.1 ml/h), the spinning performance varied greatly according to the polymer concentration. Nothing could be produced from the 10 wt% samples. For the 20 wt%, beads were observed on the collector, for the solution reached the collection electrode area before sufficient evaporation of the solvent. When the concentration became 30 wt%, fibres without beads could be produced with reproducible efficiency. For the highly entangled 40 wt% solution, the fibres were even more uniform.

In addition to the solution properties, the effects of varying voltage, solution infuse rate and working distance were assessed using the 30 wt% samples. As shown in Table 3.3, the average diameters of PU fibres were around 800 nm, but they were not significantly changed according to those parameters in our variation range.

Electrospinning is not limited to random non-woven mat. Efforts have been made to control the spatial orientation of electrospun fibres (Teo1, 2006: R89; Tan, 2007: 1330). A parallel-electrode collector is a relative simple and versatile method to prepare aligned electrospun fibres (Li, 2003: 1167). The fibres aligned across the gap between the two parallel grounded rod-like electrodes; the alignment is driven by a complex pattern of electric field, shared between these two equipotential electrodes of the collector. Using such an electrode configuration, a high degree of multiple layers of well-aligned nanofibres could be achieved (Li, 2004: 361). Two grounded parallel aluminium electrodes with a 2-cm gap were used as the collector to align our shape-memory PU. As seen from the ESEM, Fig. 3.7, well-aligned fibres were obtained from samples with concentrations of 30% and 40%. In fact, we could distinguish the alignment of the electrospun fibre mat by the naked eye. For the random orientated fibres, the mat is opaque due to the high scattering of light, but the aligned films are transparent when viewed from certain angles.



(a) **(b)**

Fig. 3.7 ESEM images of aligned SMPU fibres electrospun from solutions with different concentrations: (a) 30 wt%; (b) 40 wt%

Table 3.3 Relationship between diameters of fibres and test parameters

Infuse rate (ml/h)	Voltage (kV)	Working distance (cm)	Diameter (nm)
0.1	8.5	10	750 ±75
		15	649 ±112
		20	740 ±126
	10.0	10	768 ±113
		15	858 ±76
		20	859 ±88
	12.5	10	864 ±94
		15	736 ±95
		20	806 ±81
0.2	12.5	10	776 ±105
		15	752 ±96
		20	706 ±101
0.4	12.5	10	786 ±77
		15	647 ±126
		20	803 ±101
0.8	12.5	10	1,065 ±308
		15	761 ±107
		20	1,000 ±137
1.0	12.5	10	836 ±157
		15	841 ±161
		20	841 ±83
0.05	12.5	10	814 ±75
		15	761 ±103
		20	837 ±71

3.1.4 Conclusion

Shape-memory polymer fibres are of great potential in the future of textile industry. Not only could they be used as finishing agents to prepare high-performance fabrics, but also they are suitable for direct spinning in order to obtain active and stimuli-responsive shape memory fabrics. Both solution spinning and melt spinning have been used for this end. At the moment, thermoplastic polyurethane with semi-crystalline soft segments is the most popular choice to develop shape-memory textile fibres. According to the choice of chemical structure, such polyurethane materials could be tailored to meet the necessary requirement of spinning. Thermostability plays a major role in determining the possibility of melt spinning. Proper (high) molecular weight is important to ensure a stable flow of fibres during spinning. As demonstrated above, the shape-memory polyurethane could be electronspun into random or aligned non-woven films, which may open a new route to make use of shape-memory PU in textiles. However, a lot of work still needs to be done before the shape-memory fabric comes to the market as a finished product.

Acknowledgments We are grateful to A.R. Tajbakhsh (Cambridge) for help with chemical synthesis, G. Hebbrecht (Gent) for help with melt spinning of SMPUs and J.P. Borges (Lisbon) for helping with the electrospinning technique.

3.2 Fabric Joining Equipment Preliminary Design and Process Development

Ian Jones, Roberto Landò, Stefano Carosio, Tanya Scalia, Riccardo Baglini

Abstract New laser-bonding methods have been developed to provide greater flexibility in the design of garments and a higher degree of automation. The results of feasibility studies are described in this section followed by a description of the preliminary equipment that is now being prepared and the results of more detailed studies for textile and process definition.

3.2.1 Introduction

In clothing manufacturing, fusing refers to the bonding of an interlining to an outer textile fabric by means of an adhesive, previously applied to the interlining and that melts under certain conditions of temperature, time and pressure.

Fusible interlinings are textiles coated with an adhesive. The textile structure can be woven, knitted or non-woven. The resin is usually a polymeric material, which melts and flows within a defined temperature range. The adhesive can be applied to the textile in a variety of ways, e.g. scatter coating, dot printing, paste printing, laminating, melt coating.

The durability of a bond, obtained by fusing, depends on the materials, equipment and methods used.

The traditional fusing equipment and methods are:

1. Electric iron: This is a manual process, which relies on the operator to control pressure and time. The temperature is variable. With polyamide resins, bond formation is assisted by providing steam. The result is better if a damp cloth is used, rather than a steam iron, because the steam is more uniformly distributed.
2. Flat-bed press: With this type of equipment, pressure, temperature and time are accurately controlled. A relatively high pressure is required, which is applied either pneumatically or hydraulically.
3. Continuous fusing press: Temperature, pressure and time are infinitely variable within the working ranges. Short pressing times give a relatively gentle process. Fusing can be achieved with a significantly lower temperature of the top fabric, which helps to avoid heat stress. They are capable of fusing multiple layers together.

There are different types of fusing machines on the market. Using the appropriate pressure and keeping the temperature constant are two critical aspects of the fusing process.

The quality of the bond, in terms of resistance to washing, ironing and dry-cleaning, depends on the interlining, the adhesive, the outer layer fabric and the fusing conditions. These have to be matched to the specific requirements of a garment. The bond should be formed without modifying dramatically the appearance, the structure, the comfort and the property of the garment. Different materials react differently to heat, pressure and moisture. They may either shrink, become shiny, melt or burn. The bond made between the outer fabric and the interlining must not be weakened by maintenance operations.

Laser bonding of textile is based on a polymer welding method, Clearweld®, developed and patented by TWI. This method is based on transmission laser welding, see (Hilton et al. 2000), (Jones et al. 1999), (Toyota 1985), using a near-infrared wavelength laser and the interaction between an absorbent coating or the fabric, with the laser radiation. A schematic of the principle of the process can be seen in Fig. 3.8. This process is based on the fact that most polymers transmit near-infrared wavelengths. To be able to perform a weld between two polymers, using such a laser, there is a need to introduce an absorber at the interface between the two materials. Carbon Black has been extensively used for this but resulted in a black weld. Moreover, Carbon Black absorbs over a wide spectral range, thus limiting the efficiency of the process. A special material was developed that absorbs at one particular wavelength and does not degrade when heated. The material will thus absorb the laser radiation and generate heat, which is transmitted to the surrounding materials. As it does not degrade, it generates a clear weld. Pressure is applied during the entire duration of the process, to provide intimate con-

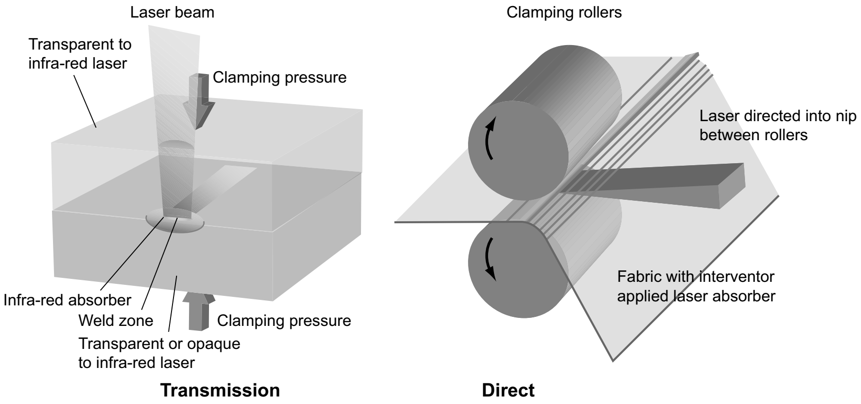


Fig. 3.8 Transmission or direct laser welding configurations

tact between the two surfaces and fuse them together. Only the materials at the interface are melted, and the external surfaces are intact. This process has already been applied to synthetic materials, for inflatable structures, furniture such as bed mattresses and protective clothing such as waterproof jacket. In the transmission configuration, an absorber is applied at the interface between the two polymers to be welded. The top material needs to transmit at least 10% of the laser radiation. The fraction of the laser beam that reaches the weld interface is absorbed by the absorber, heat is generated and a weld is obtained, as a result of the pressure applied and the heat generated. Pressure can be applied in many different ways, such as a sliding clamp or rollers.

In the direct configuration, the laser is fired directly at the interface between the two materials. The absorbing material can be coated on the fabrics or the materials can inherently absorb the laser radiation. Pressure is applied by mean of rollers.

The two textiles to weld can be either both synthetic, or one can be synthetic and the other natural. In the latter case, only the synthetic textile melts and the pressure applied bonds it to the natural fabric. The process works on knitted, woven or non-woven textiles. It leaves no or very little visible mark on the fabrics after joining.

In the case of transmission laser welding, two main configurations can be used:

- Moving samples and fixed laser beam. The parts can be positioned on a moving flat bed and the laser beam is positioned above them.
- Fixed samples and moving laser beam. The laser beam can be manipulated either by a robot, if the beam is fibre delivered, or using scanning optics.

The main difference between laser bonding and the traditional fusing technique is the application of heat to the materials. In the case of laser bonding, the energy brought to create the bond is localised and heating of the material is limited to a very small region. As a result, cooling times are much shorter than with the fusing technique. The main benefits offered by laser bonding are the following:

- reduction in production process time through automation and rapid fusing methods;
- cost savings through reduction of warehousing, cutting, handling, positioning and interlining fusing steps;
- patterning of the bonding is possible, allowing full control of the rigidity or flexibility even within the shapes being bonded;
- design flexibility;
- no or very little visible mark on the fabrics;
- additional adhesive film should not be needed at the joint;
- any change in stiffness at the joint is controllable by altering the depth or area of melting;
- the joint is permanent.

3.2.2 Concept Equipment

According to one of the main objectives of the LEAPFROG Project, an innovative fusing methodology for the interlinings and the outer fabrics has been developed. This allows significant shortening of production process and considerable cost savings, obtained by the reduction of warehousing, cutting, handling, positioning and fusing of interlinings. Steps towards industrialisation of the fabric-joining procedure will be made through construction and testing of a conveyor-based system with a laser-joining station to attach the liner fabric to the outer.

The final goal of this task is to overcome the limits of the current interliner application. The costs for managing the interliners are very high (cutting, positioning, fusing, warehousing, handling, etc.). Additionally, there is loss of quality due to the high risk of marking and soiling fabric due to the production process.

After having performed a very detailed trade-off between the current manual fusing process and the conceptual fusing-table layout, a final conceptual design for the fusing equipment was identified and chosen as the most promising. As shown in Fig. 3.9, the cell is composed of three main operation zones. Their main characteristics are summarised in the following:

- The absorber deposition zone includes a robot that drives an absorber spray head, provided by TWI. Since the spray head has to move on a plane, 3 DOF are sufficient: two for its translation and the third to fix the distance from the interlining panel surface. Several commercial robotic architectures are then available: Cartesian (3 DOF), SCARA (4 DOF), Anthropomorphic (6 DOF).
- The accurate positioning of the interliner panel must be performed by a human operator, in order to reduce the risks connected to the feasibility of the demonstrator and to overcome the problems related to a positioning granted by gravity. In this way, only a horizontal conveyer is required and will be developed.
- The laser-welding process requires a clamping system to press the panels to be joined: it is composed by a plexiglass plate, actuated by a system to regulate the pressure on the panels.

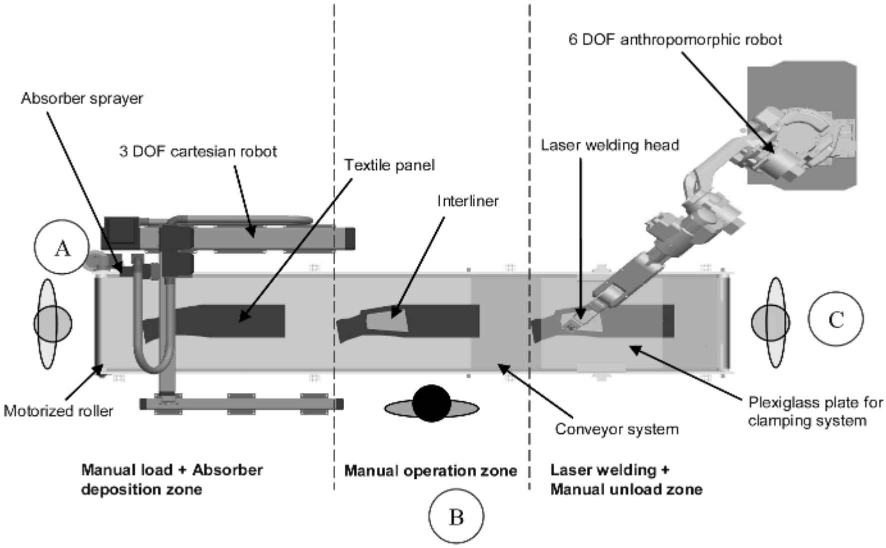


Fig. 3.9 Feasibility study last layout

With reference to Fig. 3.9, there are three working zones:

A. absorber deposition zone, equipped with a robotic system;
B. manual operation zone;
C. laser welding zone, equipped with a robotic system.

The main features of this new fusing table concept are herein described:

1. One horizontal conveyor belt to move the textile panels.
2. A robotic system, equipped with an absorber head. Possible robotic architectures are:
   - Cartesian (3 degrees of freedom – DOF);
   - SCARA (4 DOF);
   - Anthropomorphic (6 DOF).
3. A clamping system able to provide the required pressure in the welding operation, by means of a plexiglass plate. The actuation of the plate could be performed through:
   - pneumatic actuators;
   - parallelogram mechanism (see Fig. 3.10).
4. A robotic system, equipped with a laser-welding head.

With reference to Fig. 3.9, the cycle of work of the fusing table cell is described as follows:

1. The human operator positioned in ‘A’ loads the outer fabric panel on the conveyor belt.
2. The human operator loads the pre-defined trajectory into the robot controller and switches on the robot equipped with the absorber spraying head.

3. Deposition of the absorber on the outer fabric panel.
4. The human operator turns on the conveyor belt, which moves the outer fabric panel from the absorber deposition zone to the manual operation zone.
5. The human operator stops the conveyor belt.
6. The human operator, placed in ‘B’, loads the interliner panel.
7. The human operator turns on the conveyor belt, which moves the outer fabric and the interliner panels from the manual operation zone to the laser-welding zone.
8. The human operator engages the clamping system.
9. The human operator loads the pre-defined trajectory into the robot controller and switches on the anthropomorphic robot equipped with the laser-welding head.
10. Laser welding operations.
11. The human operator disengages the clamping system.
12. The human operator unloads the interliner welded to the outer fabric panel.

The described architecture should not be considered final. It could be subject to changes due to further information gained from the ongoing work.

In order to guarantee that absorber deposition and laser welding operations occur on the correct positions of the panel in work, its accurate relative positioning with respect to the two robots must be assured. This, in turn, requires that the tissues are positioned in known locations with respect to the conveyor belt in correspondence of the two robotised stations. This result may be obtained in several ways, at different levels of automation, reliability and cost. For the purpose of the activity, in order to guarantee a good reliability and usability to the fusing table cell prototype, a two-step approach has been considered. First, instead of positioning the outer fabric directly on the conveyor belt, an intermediate pallet is adopted. This solution has many advantages with respect to the direct positioning. First, the positioning of the tissue can be made off-line, with no time constraints and with high precision, provided that a sufficient number of

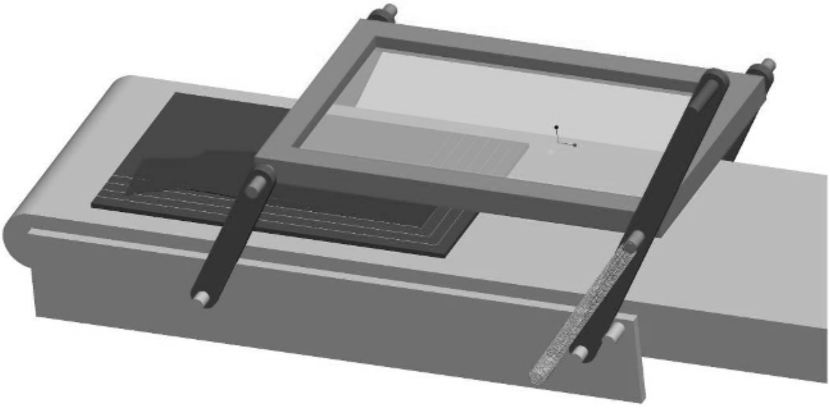


Fig. 3.10 Clamping system: mechanism solution (open position)

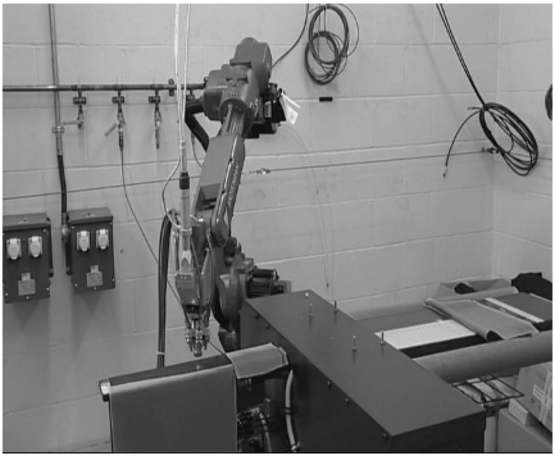


Fig. 3.11 Fibre-delivered diode laser and 6-axis robot

pallets is available. Second, no geometric references must be defined on the belt of the conveyor, in order to guarantee the position of the tissue with respect to it. Moreover, the pallet can be made in such a way to protect the belt from the laser heat in during welding operations. In general, due to the low speed and acceleration values prescribed to the conveyor drive, the tissue panel is not expected to move with respect to the panel during the belt motion, so no clamping is required between the pallet and the panel.

The bonding station consists of a diode laser and a manipulating robot. The laser used will be a 500-W diode laser from Laserline, which is delivered down a 1-mm diameter fibre. The fibre is positioned on the end of a 6-axis Motoman robot (Fig. 3.11).

The laser is equipped with an optical head that allows shaping of the laser beam in order to have a circular beam with a diameter of 5 mm on the fabrics. The wavelength of the laser beam is 940 nm. Manipulating the laser beam using a 6-axis robot allows bonding of complex patterns if necessary. In addition, an on-line control system allows monitoring of the temperature of the fabrics and adjusting of the laser power to keep the temperature constant, thus avoiding burning of the samples.

3.2.3 Bonding-Process Development

Preliminary trials were carried out to assess the feasibility of using transmission laser welding to bond the interlining of a men suit's jacket to the outer fabric. Tests were made on cotton and nylon. Strong welds with a good appearance were obtained (Fig. 3.12).

Fig. 3.12 Cotton joined to nylon using laser processing

Different materials were sourced out for preliminary laser bonding trials. Traditionally, men's suits jackets are made of up to six layers, one outer layer and up to five interlinings. The outer layer is a woven natural fabric, usually wool or cotton. The linings have different structures (non-woven, woven, knitted) and different stiffness. They are usually fused or sawn to the outer fabric. Traditional fabrics for the outer layer and the interlining were sourced for the laser-bonding trials, as well as alternative solutions. Indeed moving from traditional fusing processes to laser bonding may require a modification in the interlinings used.

To ensure that the materials sourced were suitable for laser processes, transmission measurements were carried out. Indeed, it is important that the top fabric transmits at least 10% of the laser radiation – preferably 30% if more than two layers have to be bonded together. Dark-coloured fabrics can sometimes be dyed using Carbon Black. Carbon Black absorbs the near-infrared radiation, so if contained into a fabric, the fabric will be inherently absorbent to the laser radiation. It can be damaged by the laser beam, due to over-heating, especially if the Clearweld® welding consumable is added.

Transmission trials are carried out by firing a 30-W laser pulse with duration of 100 ms. An Ophir-meter, model 30A-MD-CAL, is used to measure the power of the laser. First, measurements are made without any fabric and then a piece of fabric is placed between the Ophir meter and the laser. The fraction of laser beam that is transmitted is measured by the power meter. Transmission measurements have been made on many different types of outer fabric and interlinings.

Most of the fabrics were shown to have suitable transmission properties in the range 10–30%. Those that did not were black-coloured fusible interlinings, used for manufacturing suits using the fusing technique. It is believed that this was due to the black dye used in them, as white equivalents of those fabrics did not have any problems. However, the traditional fusing interlinings are very thin and have a low fibre-density. Laser processing of those fabrics may result in melting them on their whole thickness but with a weak joint between the interlining and the outer layer, due to the lack of density of melted material. The rest of the fabrics were suitable for bonding trials, such as thicker non-woven and non-fusing white interlining and a woven white polyester fabric, traditionally used in the manufacturing of bed mattresses. These were used to study the influence of fibre density on the strength of the bond.

Clearweld® LD120B absorber was used for the trials. The absorber was sprayed onto the fabrics, using a Sono-Tek spraying equipment (1500XL dispenser). The absorber is dispensed to the spraying head using an automated syringe, which allows accurate control over the quantity of absorber deposited. The ultrasonic nozzle of the Sono-Tek equipment uses high-frequency sound waves. A high-frequency electrical signal is sent to piezo-electric materials, which convert it into vibratory motion at the same frequency. The vibration of the nozzle tip results in atomisation of drops of absorber and an air jet propels the absorber on the fabric. The feeding rate of the syringe is around 1 ml/ min and the absorber is deposited onto a 5-mm thick line. The absorber was deposited on the interlinings, in two passes. In the case of bonding of the fabrics on their whole surface, lines of absorber were deposited on 30 × 30 cm interlining samples, two consecutive lines being separated by 3 cm. Bonding trials were first made along one line, to assess the feasibility of joining an outer fabric to an interlining. Two interlinings were tested initially: a white non-woven (PL) interlining and a white woven fabric (PL/PP) normally used for bed mattresses. Problems arose with some of the outer fabrics. It appeared that wool (even beige wool) easily burnt. It is expected that an automatic temperature control system applied to the laser in further tests will resolve this. White cotton, beige linen, and brown cashmere were welded to the non-woven interlining successfully along a line, using a laser power of 150 W, a welding speed of 3 m/min and a laser spot of 5 × 3 mm. Successful welds were obtained with the woven synthetic fabric and the same outer fabrics, with a laser power of 150 W, a welding speed of 1.5 m/min and a laser spot of 5 × 3 mm. Weld strength was assessed by hand, and it was observed that the weld was much stronger with the woven fabric as the interlining. As can be seen on Fig. 3.13, some parts of the interlining stayed on the outer fabric, after manual pulling tests. Bonding trials were then carried out on 30 × 30 cm samples, on linen and brown cashmere, with the two different types of fabrics for the interlinings, using continuous welding.

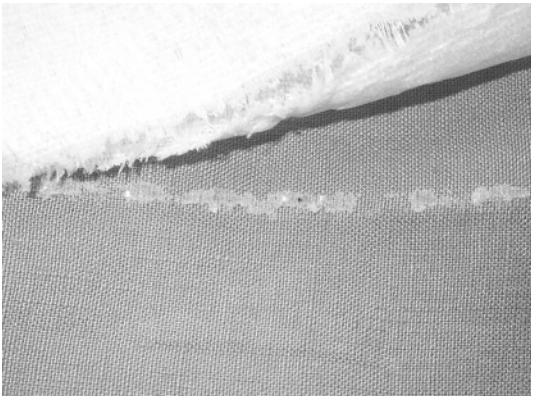


Fig. 3.13 Bonding trials sample after test between linen and woven interlining

Further bonding trials will be carried out using a range of outer fabrics and using new equipment with continuous laser power control with feedback based on measurements of the fabric surface temperature.

3.2.4 Conclusion

3.2.4.1 Equipment

The prototype demonstrator equipment for laser bonding of interlining to outer fabrics has been designed with a series of different operative zones:

1. Manual: comprising the load and unload operations, at the beginning and end of the line, the positioning of the interliner and the control of the belt and pneumatic system;
2. Automatic: spraying of the absorber, the movement of the belt, the clamping system and the robotic laser welding.

The equipment designed for the processes performs all the steps identified in the automatic operation and its control system is designed to allow the manual operators to interact with the process, as stated in the cycle of work. The prototype design has the following components. The movement of fabric panels includes:

- A belt on which the panels are positioned.
- An electric motor to move the belt. The motor is controlled by a switch to allow operators to stop the conveyor and let the operations of spraying, interliner positioning and final welding to be performed.
- Pallets with references for positioning the fabric.

The spraying operation comprises of:

- a spraying head, tubing, control system and power supply;
- architecture to move the spray head, such as a Cartesian robot with 3 degrees of freedom.

The clamping system has:

- a pneumatic circuit with an air compressor, actuators, i.e. pneumatic cylinders and a valve for controlling the actuators;

or

- a four-bar mechanism, manually moved with a spring for pressing the plexiglass with the right pressure.

Finally, the laser welding process includes:

- a laser head with temperature-controlled power modulation;
- a robotic arm (6 DOF) for moving the head.

3.2.4.2 Bonding Process

Several conclusions can be made from the bonding procedure trials carried out:

- It is possible to bond an interlining to a natural outer fabric without adhesive coatings, as long as synthetic materials are present at the weld interface or in one of the fabrics.
- Using a woven structure for the interlining gives more strength to the bond. Traditional interlinings used in men's suits should be avoided as they are easily damaged by the laser beam.
- Appropriate selection of the outer fabrics and dyes is important. It is possible to damage natural fabrics in laser processing. The use of an on-line control system, that would regulate the laser power to maintain the temperature on the fabrics constant, should avoid discrete burning. This will be implemented in the prototype equipment.

The work will continue with the construction of the prototype equipment for demonstration of the automated attachment of the interlining. This will include construction and integration of the conveyor belt, the spraying unit, clamping plate and robotically manipulated laser system. Following this there will be a series of functional tests and process demonstrations, which will be completed during 2009. Process trials will continue in the intervening period to specify laser bonding procedures for perimeter bonds and areal arrays of spot bonds. Large-scale representative samples will be prepared with a range of liner and outer fabrics using the test-bed equipment. The samples will be compared with the existing fusing methods using an aesthetic evaluation test and an adhesion strength test. An exploration of the wider more innovative possibilities will also be carried out, including altering bonding patterns within a piece of fabric, through variation of the density of sprayed laser beam absorber and patterns of energy delivered to the fabrics. This will allow stiffness and flexibility in different areas to be controlled as was never possible using the current interliner-fusing methods.

3.3 Stiffening Agents and Process in Clothing

Pierandrea Lo Nostro, Alessio Becheri, Luca Giustini, Lucia Rodrigues, Angela Mendes

Abstract The achievement of enhanced performances in automated garment making is related to the use of permanent and temporary stiffening agents. The permanent stiffening agents are related to the reduction of the complexity and the number of parts to be sewn together required in particular for the interlinings that have to maintain a pre-defined shape (plastron, shoulders …). The temporary stiffening agents are required to facilitate automated material handling and sewing, including physical removal after garment integration. The analyses of stiffening agents for temporary and permanent application were carried out considering different types of

stiffening agents, specific for various textile substrates (cotton, silk, wool and polyester). We use water-based solutions or dispersions of various stiffening substances (Carboxymethylcellulose; 2-idroxyethylcellulose; modified cellulose; VINAVIL®; NEXTON (hydrophobically modified hydroxyethylcellulose); PEG (different M.W.); sodium chloride (saturated solution); albumin; sucrose (saturated solution); polyvinylpyrrolidone; poly (methacrylic acid); chitosan (high and low M.W.) and solutions of nanoparticles (ZnO and Al_2O_3). Many stiffening solutions have proved to be highly promising for permanent and temporary stiffening applications. Stiffening agents effects can be analysed through fabric assurance by simple testing (FAST). Each test gives the 'fabric fingerprints', invaluable information to predict how the fabric will perform when made-up into a garment. This method allows the comparison of the traditional interlining and innovative methods.

3.3.1 Introduction

In a classic men's jacket some parts must be stiffer than others, in order to impart a desired shape or to increase the durability of some parts against wearing (Fig. 3.14). Usually, manufacturers use interlinings, multilayer samples or chemical solutions for stiffening applications. The aim of this work is to test different stiffening agents for woven fabrics used in man's jackets, both for permanent and temporary applications. Important requirements are: the compatibility with the fibres, toxicity for the environment, costs, and water solubility (especially for temporary stiffening applications).

Permanent modifications of textiles are also required for the substitution of interlinings and multilayer samples on a men's jacket. Temporary modifications of textiles are required to facilitate automated material handling and sewing, including physical removal after garment integration.

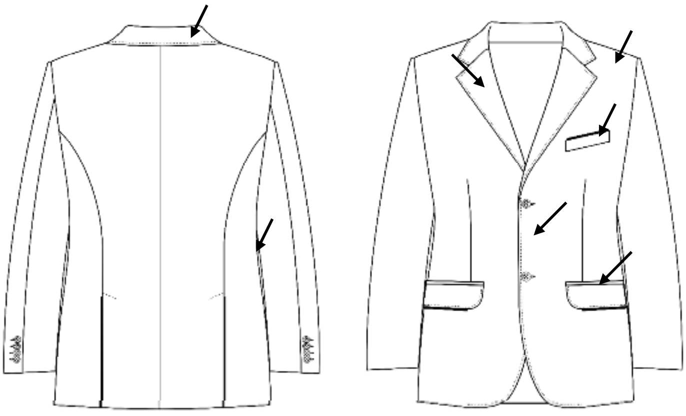


Fig. 3.14 Positions of interlining in a men's jacket

The basic guideline is to avoid the use of toxic agents for the environment and for human health. The jacket in fact is in contact with the human body, and washing out the stiff agents may result in pollution.

3.3.2 Materials and Methods

Wool, cotton and polyester samples were received from Grado Zero Espace (GZE, Italy) and treated with different stiffening agents.

A jacket for a men's suit is composed of a number of different materials, as detailed in Table 3.4.

Table 3.4 Different materials constituting the jacket parts

Outer material	Wool (worsted yarn), mixed constitutions
Inner lining	Acetate Satin, Viscose, Polyester
(Fusible) Interlinings	Plastron, Reveres' and Collar of a combination of different materials like non-woven (Peps/Pa) woven (Co/horse yarn)

In the past, starch was commonly used as a stiffening agent. Starch is a polysaccharide carbohydrate consisting of a large number of glucose monosaccharide units joined together by glycosidic bonds. It is water-soluble and non-toxic.

We tested several kinds of different stiffening agents. These are all water-soluble, and non-toxic for the environment. Among these, carboxymethylcellulose (CMC), 2-Hydroxyethylcellulose, modified cellulose, albumin and sucrose (saturated solution).

We also tested commercial vinyl glue (VINAVIL®), polyethylene glycol with different molecular weights (400, 1,000, 1,500, 2,000, 3,335 and 8,000 g/mol), propylene glycol, sodium chloride, trichloro-triazine, slaked lime, rabbit skin glue and urea.

The treatments were performed by spraying, soaking and brushing at different temperatures (24–130°C).

The sample size was 10 × 10 cm and 40 × 60 cm (required for the FAST testing technique and the application equipment was upgraded according to the foulard technique).

We studied the temporary stiffening agents with the vapour stream method, and tried to identify agent compatible with dry cleaning.

3.3.3 Results and Discussion

The treated textile materials were cotton, wool and polyester. Therefore, these had to withstand:

- an optimal temperature range (cotton 180˚C, few seconds, wool 100˚C, polyester 120°C);
- compatibility with organic solvents, glues, chemicals;
- water intrusion in order to ensure a homogeneous and deep distribution of the stiffening agents.

In order to deal with the above-mentioned requirements, two alternatives have been identified:

- Use a fabric-specific application methods and/or stiffening agents;
- Select a universal application technology and agent. This limits the application methods of interest to dry, surface-limited processes.

The selection of the application process for temporary and permanent stiffening agents has been approached from different perspectives described below, in order to select the most suitable process for each material:

1. Functional level: considering which are the types of effects that must be produced and which detrimental effects shall be prevented, process selection is performed accordingly;
2. Type of stiffening agent: the application method must be appropriate for the stiffening agent in terms of both stability and viscosity; up to a certain amount, the materials properties can be tuned in accordance to the processes to be adopted;
3. Quality of the fabric: the nature of the fabric imposes restrictions (wettability, temperature range, nature of solvent or of solute) on the application method;
4. Quality of the final product (garment): the nature of the stiffening agent and the application method must allow the maintenance of fabric (garment) final properties (pilling, fastness, resistance, comfort, etc.).

The starting point for the selection of the proper stiffening agent, and the related deposition process, is based on the two main families of agents under study to be employed for different purposes:

- Solvent-based organic components (starches, amines, chitosan or similar) for temporary and permanent stiffening of the fabric during garment manufacturing;
- Solvent-based organic components, insensitive to environmental changes or washing processes.

Solution-based stiffening agents are rather viscous. Diluted dispersions have lower viscosity, but on the other hand they may have stability limitations, due to settling or phase separation. Health and safety issues act as really important players when organic solvents are used.

The best stiffening results for cotton, wool and polyester are shown in Tables 3.5–3.7.

Figures 3.15–3.20 illustrate the stiffening effect in cotton, wool and polyester treated with VINAVIL 10%.

Table 3.5 Cotton best results

Stiff. agent	Conc.	Appl. method	Appl. time	Appl. temp.	Drying temp.	Drying time
Carboxymethyl cellulose	1% sol. in water	Spray	/	RT	RT	24 h
VINAVIL®	1% sol. in water	Spray	/	RT	55°C	15 min
VINAVIL®	1% sol. in water	Soak	10 min	RT	55°C	15 min
VINAVIL®	1% sol. in water	Spray	/	RT	120°C	1 h
VINAVIL®	10% sol. in water	Soak		RT	120°C	1 h
VINAVIL®	20% sol. in water	Soak		RT	120°C	1 h
Sodium Chloride	sat. sol. in water	Spray	/	RT	130°C	15 min
Albumin	2% sol. in water	Soak	60 min	RT	60°C	15 min
VINAVIL®	10% sol. in water	Soak	10 min	RT	130°C	15 min
Carboxymethyl cellulose	2% sol. in water	Soak	10 min	RT	130°C	15 min
Poly methacrylic acid	1% sol. in water	Soak	30 min	RT	130°C	15 min
Polyvinyl pyrrolidone	5% sol. in water	Soak	40 min	RT	130°C	15 min
Ticaxan®	0.1% sol. in water	Spread	/	RT	130°C	15 min
Chitosan (low M.W.)	1% in 1% acetic acid water sol.	Spread	/	RT	130°C	15 min
Chitosan (high M.W.)	1% in 1% acetic acid water sol.	Spread	/	RT	130°C	15 min

Table 3.6 Wool best results

Stiff. agent	Conc.	Appl. method	Appl. time	Appl. temp.	Drying temp.	Drying time
Sodium chloride	sat. sol. in water	Spray	/	RT	60°C	15 min
Albumin	2% sol. in water	Soak	15 min	RT	60°C	15 min
Poly methacrylic acid	1% sol. in water	Soak	60 min	RT	130°C	15 min
Polyvinyl pyrrolidone	5% sol. in water	Soak	40 min	RT	130°C	15 min
Chitosan (high M.W.)	1% in 1% acetic acid water sol.	Spread	/	RT	130°C	15 min
VINAVIL®	10% sol. in water	Soak	25 min	RT	130°C	15 min

Table 3.7 Polyester best results

Stiffening agent	Conc.	Appl. method	Appl. time	Appl. temp.	Drying temp.	Drying time
VINAVIL®	10% sol. in water	Soak	5 min	RT	120°C	1 h
VINAVIL®	20% sol. in water	Soak	5 min	RT	120°C	1 h
VINAVIL®	1% sol. in water	Brushing	5 min	RT	120°C	1 h
VINAVIL®	2% sol. in water	Brushing	5 min	RT	120°C	1 h
VINAVIL®	5% sol. in water	Brushing	5 min	RT	120°C	1 h
VINAVIL®	10% sol. in water	Brushing	5 min	RT	120°C	1 h
VINAVIL®	20% sol. in water	Brushing	5 min	RT	120°C	1 h

Fig. 3.15 Untreated cotton

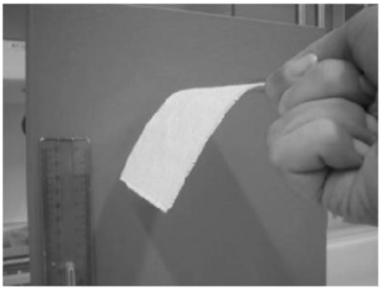


Fig. 3.16 Cotton + VINAVIL® 10%

Fig. 3.17 Untreated wool

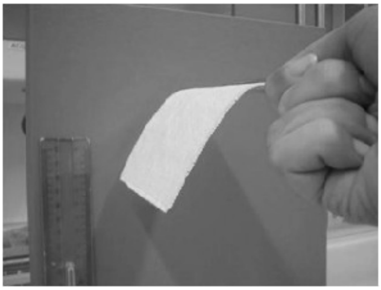


Fig. 3.18 Wool + VINAVIL® 10%

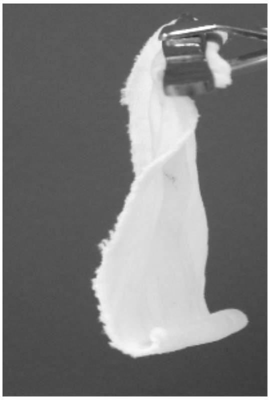


Fig. 3.19 Untreated polyester

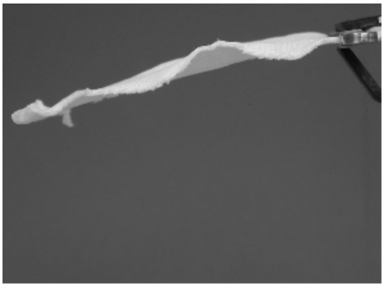


Fig. 3.20 Polyester + VINAVIL® 10%

Since the temporary stiffening requires the removal of the stiffening agent with a quick and efficient method, in our laboratory we carried out this step using a steam cleaner (see Fig. 3.21).

Cotton samples treated with VINAVIL® and Chitosan 1% were still stiff after the steam treatment. The other samples returned to their original stiffness.

Fig. 3.21 Steam cleaner

3.3.4 Conclusions

Two formulations gave the best results in terms of permanent stiffening effect on cotton:

1. 1% chitosan (high molecular weight) in 1% acetic acid water solution. The application method is: spread onto the fabric (10 × 10 cm) surface, and then dry at 130°C for 15 min;
2. 1% VINAVIL (commercial vinylic glue) water dispersion. The solution was sprayed onto the fabric surface and then dried at 130°C for 15 min.

Dispersion (1) is rather viscous, while solution (2) is more fluid. The second one allows an easier penetration and makes the spraying procedure more homogenous and with better results.

The other stiffening agents applied on cotton, wool and polyester, were removed from the textile fabrics after steam treatment.

With regard to the stiffening effect, the following aspects have to be highlighted:

- The distribution of the applied stiffening agent can be just on the surface, or also in the fabric matrix. Our results are based on fabric soaking, so the effect of the uptake within the fabric was considered. The uptake and therefore the stiffening effect are different when dyed and finished fabrics are used. With regard to the stiffening effect, it appears to be favoured when the fabric is soaked in the stiffening agent dispersion, but this treatment will make the following removal more difficult.
- Amount (dry weight) necessary for obtaining the desired effect; it is not yet defined the final amount to be applied on the surface, because this depends on the required temporary stiffness level. Typical treatment with cotton and the

chitosan solution results in a weight increase of 1.06%; while the treatment with the carboxymethylcellulose solution results in 1.32%, and treatment with the VINAVIL dispersion resulted in a weight increase of 3.94%. This means that for solutions a) and b) the amount of liquid to be added equals the whole fabric weight, for solution c) it is about 40% of the fabric weight. Similar amounts are needed in the case of wool.

- Precision of the added amount. No fixed criteria for the required stiffness effect are known: according to the first testing results an idea regarding the effect of stiffening materials uptake was evaluated; so far the result seemed to define a low sensitivity of stiffening effect to the amount precision. So no criteria can be set with regard to the precision of the amount added.

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Chapter 4
Virtual Prototyping: From Concept to 3D Design and Prototyping in Hours

4.1 From 3D Design to 2D Patterns Involving Realistic Drape/Fit and Comfort Simulation

Yaron Goldstein

Abstract The use of 3D computer-aided design (CAD) solutions in the apparel industry is still lagging behind in comparison to other industries (such as, e.g. the automotive). The technological challenges in many aspects are more complex, two of which are more prominent, namely (a) the re-construction of a 3D (three-dimensional) human body on a computer system, (b) the 3D simulation of soft materials (simulation of garments made of cloth). The goal of this section is to present a comprehensive methodology for garment design *effected directly in 3D,* to be used throughout the process of product design and product development. No physical prototypes will be necessary for this process as they will be re-placed by virtual prototypes. The aim is to offer a new approach to reduce the time-consuming tasks of design and prototyping currently based on 2D CAD systems and physical samples.

4.1.1 Introduction

The first CAD/CAM tools were presented to the fashion and textile industry during the 1970s. This process followed the advancement made in the microchip and computer technology as well as the professional software industry. CAD software has become the most important tool in disciplines such as engineering and architecture. In the fashion industry it is used mainly in the pattern making and development processes as well as the grading and eventually cutting process. CAD tools have since greatly evolved and new techniques and capabilities were introduced,

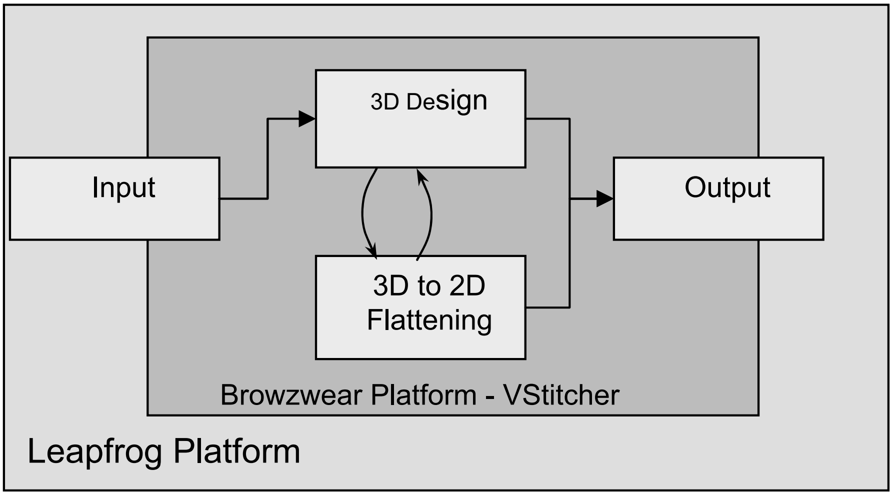

Fig. 4.1 General workflow of the direct 3D design process

while in the fashion industry the advancement are relatively slow and lag behind. Analysing the evolution of such CAD systems in other industries the transition from 2D design to 3D began more than 15 years ago and today leading companies in different areas such as PTC and SolidWorks in Mechanical CAD tools for engineering and AutoCAD of AutoDesk for architecture are offering 3D tools for design and analysis. Today, all instruments, machines or any other composite product be it a cellular phone to a jet airliner undergoes 3D design and 3D development from the first conceptual stages through design, manufacturing and construction. Moreover, new tools for more artistic purposes have been introduced over the past ten years for direct 3D design. Tools such as MAYA of Alias (AutoDesk), 3D MAX of Discreet (AutoDesk), and Softimage of Avid have become widespread and very popular.

Although cloth-drape simulation has been studied and has undergone extensive research in academia over the years, only at the beginning of this century were the first commercial solutions presented to the market by companies such as Toyobo, PAD Systems and others.

Browzwear presented its first commercial application VStitcher™ in the second half of the year 2001. VStitcher™ enabled the 3D simulation of garments from 2D patterns on a 3D parametric human figure (Avatar). Since then, this market is evolving and it is commonly accepted that design process and prototyping cycles through development will become more 3D computer aided and will reduce significantly both the design cycle time as well as the number of prototypes made per design. Looking forward, the market is now searching for more user friendly and intuitive tools to streamline the production of garments with conventional methods that are being employed today.

The goal of this section is to present a comprehensive methodology for design in 3D, offering the use of direct 3D design tools throughout the process of product design and product development. No physical prototypes will be necessary for this process as they will be re-placed by virtual prototypes. The aim is to offer a new approach to reduce the time-consuming tasks of design and prototyping currently performed based on 2D CAD systems and physical samples.

The following diagram shows the general work flow of the intended new CAD methodology. The input is normally a 2D description of a generic garment (a garment block) from which a 3D model is derived. The user modifies the 3D model, the resulting changes to the 2D patterns are automatically derived, a new 3D model is constructed and the process goes on until the designer is satisfied with the result (see Fig. 4.1).

4.1.2 State-of-the-Art

There are two prevailing approaches to meet the challenges of (a) the accurate computer representation of a human body (avatar) and (b) the realistic simulation of the drape of a garment on an avatar.

The first addresses more the first stages of the process, namely the design process and demonstrates the ability to process 2D sketches and automatically extract the 3D representation from a sketch. This approach is well described by (Turquin et al. 2004). The designer may draw a sketch of a garment with minimum constrains, using a set of relatively small numbers of drawing rules, the computer then re-constructs this sketch on an avatar by using a proximity algorithm.

Another approach for 3D design is the manipulation of pre-defined 3D representations of modifiable and parametric 3D garments. This approach is presented in articles by Bonte et al. (2000) and Wang et al. (2003). The starting point of this approach is a 3D representation of a garment, which is manipulated to a certain extent according to the designer's instruction and the body shape. Some tools are provided to create external changes to the pre-defined objects such as cuts and pleats.

4.1.3 Market Research

4.1.3.1 First-Stage Interviews

Interviews with 15 Browzwear clients were conducted to understand the process that these entities undergo while developing a new line of garments. In addition, it was important to pin point the crucial and immediate needs in respect of 3D design. The following key questions were the main issues discussed during the interview:

Table 4.1 Main Issues discussed during interviews with customers – First stage

	Key questions	Conclusions
1.	Is design in 3D as a concept, a valid and sought-after tool and what benefits on the overall process are expected?	• 3D design tools are valid as an important development. It is perceived as a natural development of current tools as well as to embody high potential in improving the efficacy of key factors of the design and development process of garments. • More control of the finished products is expected. • Significant reduction in cycle time per garment.
2.	Where and how should a 3D design tool be integrated in the current workflow of the organisation?	The 3D design tools should be integrated within existing tools. CAD systems such as Lectra, Gerber, Asysst and others are being used extensively by the industry. 3D design tools will not re-place these tools but be synergic to them. Thus, strengthening the knowledge base and know how as well as the core business competence of the companies.
3.	Who should be the operator of such a tool?	• The operators of such tools are expected to be pattern makers and technical designers. Designers at least in the first stages will continue using 2D design tools (Freehand, Illustrator, etc.). • Is conceived as a professional tool, which will need training and computer competence.
4.	What are the expected features?	• Existing 3D design capabilities should be integrated in to these new tools. • Design and pattern modification tools should be provided in an intuitive 3D interface enabling the manipulation the 3D representation of the Garment.
5.	How will it affect the current systems used in the organisation?	• More use of the existing CAD systems as 3D tools are expected to re-establish the control over the manufacturing and development process of a garment. • Over time it will lead to a comprehensive change of the design and prototyping process and hence it will change conventional 2D design methods.
6.	Are the existing 3D tools providing features that will need to be integrated in the future 3D design tool?	All capabilities that are being presented by concurrent 3D tools are expected to be integrated in new 3D design systems.
7.	Is a 3D design tool expected to be a standalone tool or integrated in current 3D applications.	For pattern makers and technical designers it should be part of the standard process, while for designers a standalone tool is expected.

4.1.3.2 Second-Stage Interviews

At a second stage, after establishing the desired methodology Browzwear re-interviewed 10 clients, already involved in first-stage interviews, and 3 new clients to identify and validate features, tools and work flow. The following key questions were the main issues discussed during the interview:

Table 4.2 Issues discussed during interviews with customers – Second stage

	Key questions	Conclusions
1.	Which garments are conceived as basic blocks?	• The following garments are the most essential building blocks for design: dress, skirt, shirt and pants. It is conceived that by just using these basic primitives, most of the garment designs could be made. • Additional primitives may extend the above list thus shortening considerably the work process: collar item, buttoned shirt, jacket, tights, jeans, and hoods.
2.	What features and manipulation are needed and expected?	See the feature list below (1–6, Sect. 4.1.4.2). In general, the concepts should be the same as or an extension of the tools existing in 2D CAD applications.
3.	What features are considered as a must?	See features 1–6 below (Sect. 4.1.4.2).
4.	What is the level of complexity that will be accepted?	It is conceived as a professional tool, which will need training and computer competence.

4.1.4 Methodology

4.1.4.1 Approaches – Pros and Cons

As discussed in Sect. 4.1.2, two approaches stand out when trying to encapsulate the discussed challenges. The first addresses more the initial stages of the process namely the design process and demonstrates the ability to convert 2D sketches and automatically extract the 3D representation of the sketch. The other is the manipulation of a pre-defined 3D representation of a modifiable and parametric 3D garment.

The market research clearly indicates that although the more intuitive approach of using 2D sketches to create 3D design seems very appealing, it is not in line with the existing work process of the industry, nor does it approach the target users namely pattern makers and technical designers. It also seems to be more difficult to implement due to many as yet unclear technological aspects. Although the 2D sketching approach seems intuitive, designers still conceived it as too extreme for their needs. It is also our opinion that this approach will not lead to a significant reduction of cycle time and will not be easily integrated to the current development processes.

The second approach, i.e. using pre-defined 3D garment primitives as a starting point for design, is a more technical approach that fits well to the current workflow followed during garment development. In many respects it is an extension of the 2D operation done in conventional 2D CAD systems. It is, however, too technical a process for designers and they may reject using these tools as design tools. They would instead prefer using these tools as early-stage monitoring tools of the work done by a pattern maker. The 3D design tools hence are conceived as professional tools for pattern makers and technical designers that will enable them to efficiently produce virtual prototypes following the initial design process, instead of using a physical sample. Digital samples will be produced that will be later modified according to design needs and constrains or fit and comfort constraints.

4.1.4.2 Overview of Selected Methodology

Browzwear favours the approach of working directly in a 3D environment, rather than starting from a 2D sketch. In this approach, a standard 3D object (garment block created from basic pre-defined 2D patterns.) is chosen as a basic primitive with which the process begins. The main features of the selected methodology are listed in the following set of guidelines:

1. Use pre-defined 3D garment blocks.
2. Work on the existing platform and technology available at Browzwear.
3. Enable as much freedom as possible for the operator (manipulation should not be based on pre-defined control vertices).
4. Provide marking, cutting, extending, painting etc.
5. Enable texture and fabric manipulation.
6. Target technical garments designers and pattern makers.

4.1.4.3 3D CAD Software Overview

The 3D CAD software developed in LEAPFROG consists of 3 basic building blocks:

1. input module
2. 3D design module & 3D to 2D module.
3. output module.

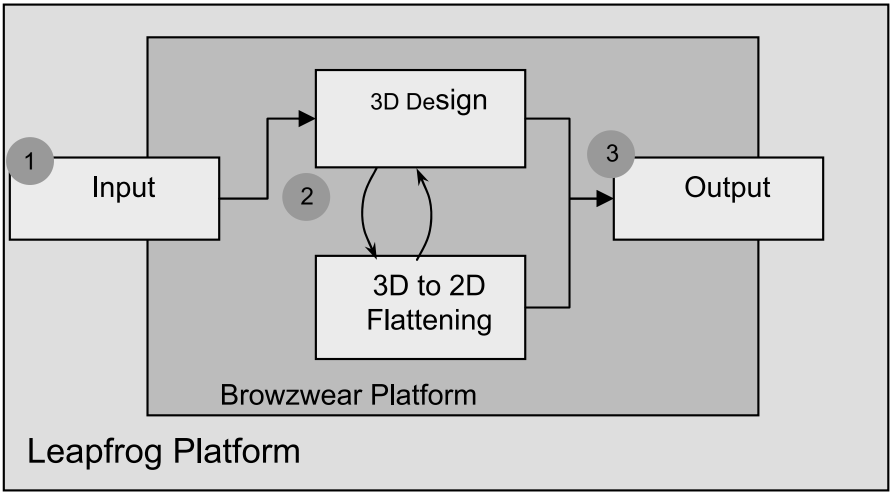

Fig. 4.2 3D CAD software overview

4.1.4.4 Input Module

The LEAPFROG platform (see Sect. 4.3) will provide 3 main data sets as input (marked 1.1 on Fig. 4.3), namely:

- fabric properties;
- body morphotypes;
- garment type (basic 3D block).

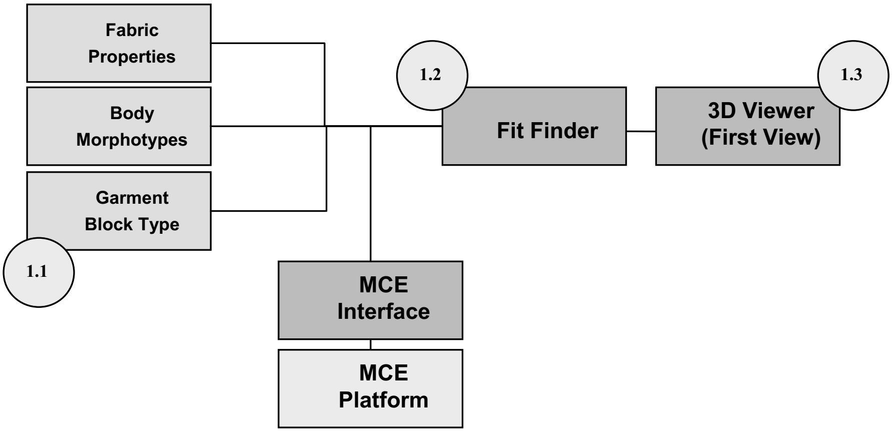

Fig. 4.3 Block diagram of input module (marked 1 on Fig. 4.6). MCE stands for manufacturability and cost model estimation, an external web service, part of the overall LEAPFROG virtual prototyping platform (see Sect. 4.3)

Each of the above 3 data sets may be delivered in more than one acceptable format, according to pre-defined conventions.

The data will feed the fit finder module (marked 1.2 on Fig. 4.3) and presented on the screen in 3D (marked 1.3 on Fig. 4.3). Fit finder will determine automatically the best configuration of garment size and morphotype.

An additional extension of the input module is the interface into the MCE platform.

The user may decide to choose a different set of garment size and morphotype 'overruling' the fit finder algorithmic output.

4.1.4.5 3D Design Module

3D Design – Overview

The 3D Design Module enables the manipulation of garments and designs through a 3D interface directly on the 3D representation of the garment (on screen).

All the 3D manipulations done during the design process are automatically converted by the 3D to 2D module to their 2D representation. In some cases the 3D design process will activate an 'on the fly' iterative simulation process, namely a sequence of iterative 3D to 2D steps and the back in order to validate the design result in 3D.

3D Design – Basic Features

The following is a list of features introduced in the 3D design process:

- 3D line marker;
- cut, drill, surface removal;
- marking of 3D point/edge/circumference/area;
- pin point/edge/circumference;
- move – point, edge, circumference;
- mark and create: iron line, pleats, darts;
- texture manipulation;
- fabric manipulation;
- fabric orientation manipulation (grain line);
- delete seam/shape.

Features Description

3D Line Marker

The 3D line feature enables the marking of a line on the 3D representation of the garment. Lines are defined by sparse points that are subsequently interpolated with the application of a linear or spline algorithm between each two adjacent points. Another option of drawing a line in 3D space is to follow the shortest path between points marked on the 3D garment.

Lines can be drawn directly on the mannequin. Circles or ellipses can be generated automatically around the mannequin limbs, torso and neck by marking that body part and adjusting the radius of the circles/ellipse on an automatically generated plane, normal to that body part.

Cut, Drill and Remove Operations

Cutting operations are implemented as a virtual scissors, by marking the cutting line with a 3D Line and cutting the shape accordingly (Keckeisen et al, 2004). Another method is to intersect surfaces between pre-defined primitive surfaces or 3D objects (like a cylinder, cube, etc.) in order to define the cutting line as the intersection of the garment with the cutting shape (Wang et al., 2003). The new edges of the cutting line can be immediately sawn with each other, by automatically defining a seam in 3D, so the overall garment look is not changed.

By marking a closed cutting line and removing the internal shape, an opening or gap is created in the shape.

Marking Tools – Point, Edge, Circumference and Area

All point, edge and circumference operations need to have an efficient 3D marking and identifying tools that will correspond directly to the 2D shapes elements. Marking will always precede a manipulation action. Any action on the 3D marked element will be applied to the corresponding 2D edges. Pinpointing will inherit the marking-tool capabilities.

Circumference marking can be achieved by a closed line going around the garment. The closed line can be defined by selecting at least 3 points on the garment, and intersecting the plane they define with the garment.

Move – Point, Edge, Circumference

A marked point, edge or circumference may be translated in the 3D environment freely with an influence zone that will be pinned. A relaxation flattening module will be needed after those freeform manipulations to re-create valid 2D shapes. The user may choose to follow the existing garment surface or the avatar body surface.

Texture and Fabric Manipulation

Each garment surface (including prints, trims, seams, etc.) may be covered with a texture corresponding to the actual scan of the fabric. Textures may be manipulated with operations such as moving, changing repeats and rotate. In addition each garment surface may be attributed with a set of physical properties that will be used while simulating the drape of the garment.

3D Maps

Additional garment information is gathered during the simulation process. The pressure map indicates points and areas of pressure applied by the garment on the body of the avatar. The tension map displays the horizontal and vertical tensions of the fabrics.

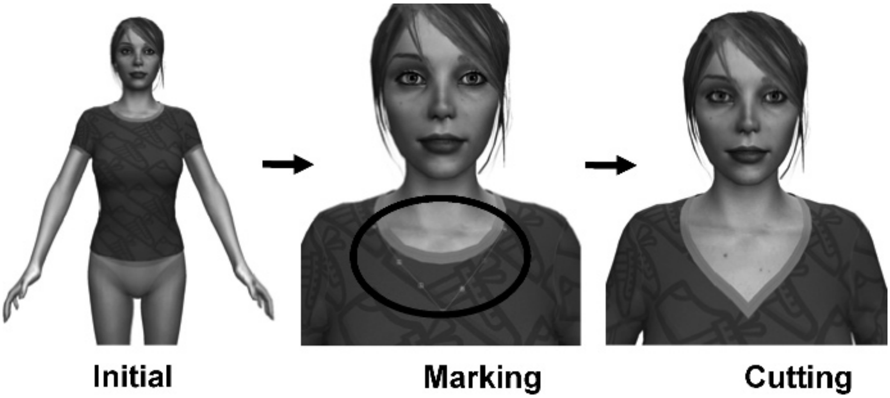

Fig. 4.4 Mark and cut garment operations

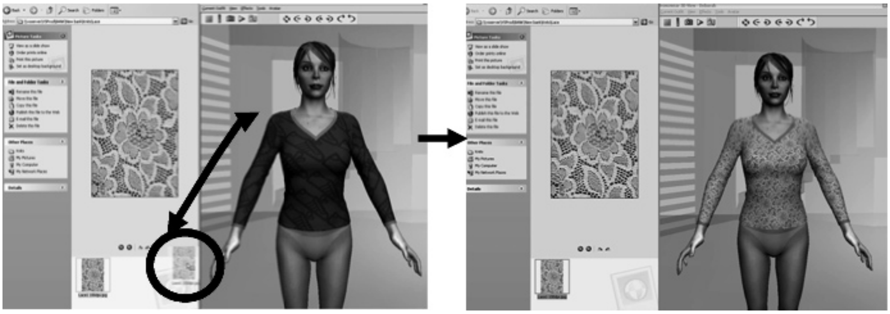

Fig. 4.5 Drag and drop a new texture and/or fabric

Fig. 4.6 Pressure map

4.1.4.6 Output Module

A block diagram of the output module is depicted in Fig. 4.7. The output module generates the following data sets:

- a set of 2D pattern pieces to be used as part of the overall production process of garments;
- a suitable 3D representation of the garment for the animation module;
- images, flash sequences, 3D files and 3D garment files.

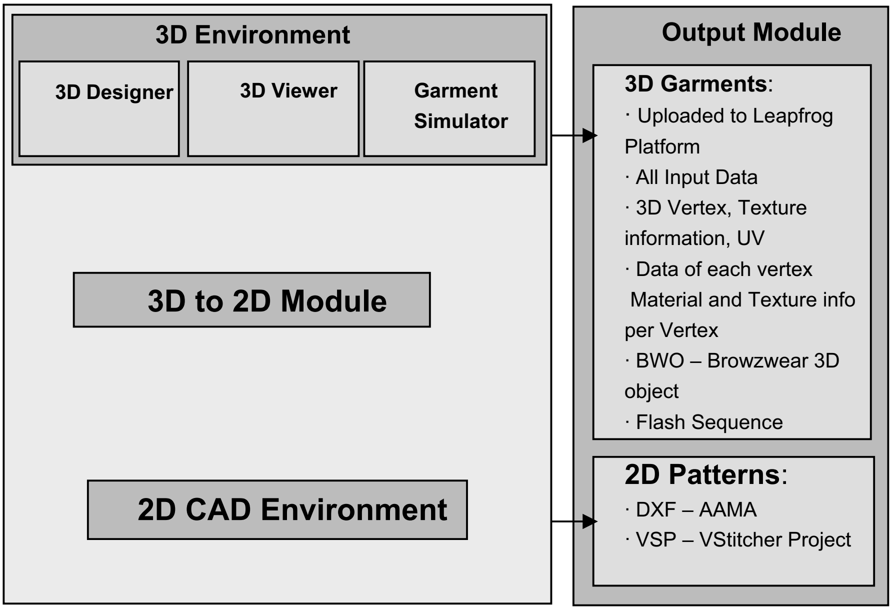

Fig. 4.7 Block diagram of the output module

The 3D CAD output is integrated into the LEAPFROG CVP (Collaborative Virtual Prototyping) platform (see Sect. 4.3), by the use of web services provided by the CVP.

4.1.5 Conclusions

Design of a garment directly in 3D is a sought-after technology that is welcomed by the fashion industry as a concept. The aim is to reduce the design and prototyping cycle time and significantly simplify the process that currently relies on physical samples and fit sessions. However, in order to introduce practical tools it is evident that this process has to fit to the current garment development process rather than change it completely. In some respects the new 3D CAD systems are expected to mimic the physical process of prototyping and turn it to a digital process with all its benefits, including the ability to collaborate in real-time at different locations.

An additional benefit of such tools is the re-gaining of garment assembly data (patterns), which in many cases are shifted to the vendors rather than being held by the brand. This gives the brands more control on their assets and strengthens their know-how.

The target users of these tools are pattern makers, technical designers and designers. It is expected, however, that once these tools are assimilated in the production process, a wider range of benefits and users will have access to such solutions.

In LEAPFROG some of the wider range benefits are being offered as an overall solution (the CVP platform). Manufacturability prediction, cost estimation, on-line fabric libraries, animation facilities are only part of these offerings.

The launching of a working prototype of a 3D Design system will validate the concepts presented in this methodology. A better understanding of the operational aspect of these tools will further enable the development of a fully functional application. Industry feedback is crucial to understand the real value and place of these tools.

4.2 Deriving Representative Human-Body Morphotypes From Scanner-Based Sizing Surveys

Patrick Robinet

Abstract In today's apparel market, consumers desire to customise more and more the style, fit and fabric/colour of the garments they buy. Most consumers of ready-made garments, on the other hand, require high-quality garments at a medium price and with the guarantee of good fit. In order to satisfy these needs, it is important to design garments according to realistic body shapes. This section presents a methodology to perform scientific body shape analysis for representative female and male populations from sample data obtained during the recent French Anthropometric Survey. The statistical estimation of representative body shapes is based on comprehensive and updated 3D anthropometric databases. This research was carried out by the French Textile and Clothing Research Institute (IFTH) as part of the LEAPFROG project in the course of two consecutive years.

4.2.1 Introduction – Statistical Methodology to Define Body Shapes

Even though industries like fashion, fitness and apparel manufacturing and retail use descriptions of human-body types for different purposes, their body-type classifications are quite similar. In most of the cases these classification schemes are based on different symbols or icons, such as:

- alphabetic symbols (H, O, A, X, R, I, S …);
- geometric shapes (rectangular, oval, triangle …);
- names of fruits (apple, pear …).

This section describes a methodology for the scientific analysis of human body shapes for both the bust–hip part (torso), as well as the whole body (male and female). The proposed methodology is associated to sizing systems. Simmons, and Istook, (2003, August). The body measurements of the sample population have been derived from whole-body scanners during the French sizing survey. A number of similar studies have been published in the past on such topics, e.g. (Simmons and Istook 2003).

Clustering (or cluster analysis) is a data-mining technique that deals with the extraction of the implicit knowledge, data relationship or other patterns not explicitly stored in databases, by grouping related records together.

A cluster is defined in statistics as a collection of objects that are similar to one another. The goal of clustering is to find intercluster similarity and intracluster dissimilarity, through the discovery of a hidden pattern that gives meaningful groups (clusters) of objects (in our case, the objects are the people of the sample).

The advantage of using the clustering approach is that we can detect the natural groups, in the form of clusters, as based on different body types, together with other information such as anthropometric ratio characterisation, etc.

Hierarchical clustering methods are used to build a cluster hierarchy, i.e. a tree of clusters also known as a dendrogram. Hierarchical clustering methods are categorised into agglomerative (bottom-up) and divisive (top-down). In our case, the agglomerative method was used. An agglomerative clustering starts with one-point clusters and recursively merges two or more most appropriate clusters. Hierarchical methods provide ease of handling of any form of similarity or distance. It is applicable to various attribute types. However, most hierarchical algorithms do not re-visit and improve intermediate clusters after their construction. The algorithm used in our analysis takes into account the consolidation of the partitioning and improve the quality of the clusters.

A typical anthropometric database has a huge attribute set that needs to be considered when finding clusters. There are a maximum number of attributes above which the performance of the clustering algorithm will degrade rather than improve. To create good clusters, our initial task was to reduce the dimensionality of the data set and find the clusters in a new attributes a space with reduced number of dimensions.

Various techniques for dimensionality reduction are available, the most important being principal component analysis (PCA). This technique of statistics is used in most descriptive analysis cases. It consists in representing under graphic forms information contained in a database. It allows showing a space in p dimensions with the help of areas of smaller dimensions.

Generally, 7 to 9 body-shape categories (morphotypes) are used in the fashion industry, such as, e.g.: hourglass, bottom hourglass, top hourglass, spoon, rectangle, oval, triangle, inverted triangle. Figure 4.8. below lists the main steps in the clustering methodology that was followed in order to derive representative body-shape clusters (morphotypes), based not on empirical classifications as the one above, but on the statistical analysis of actual sample data.

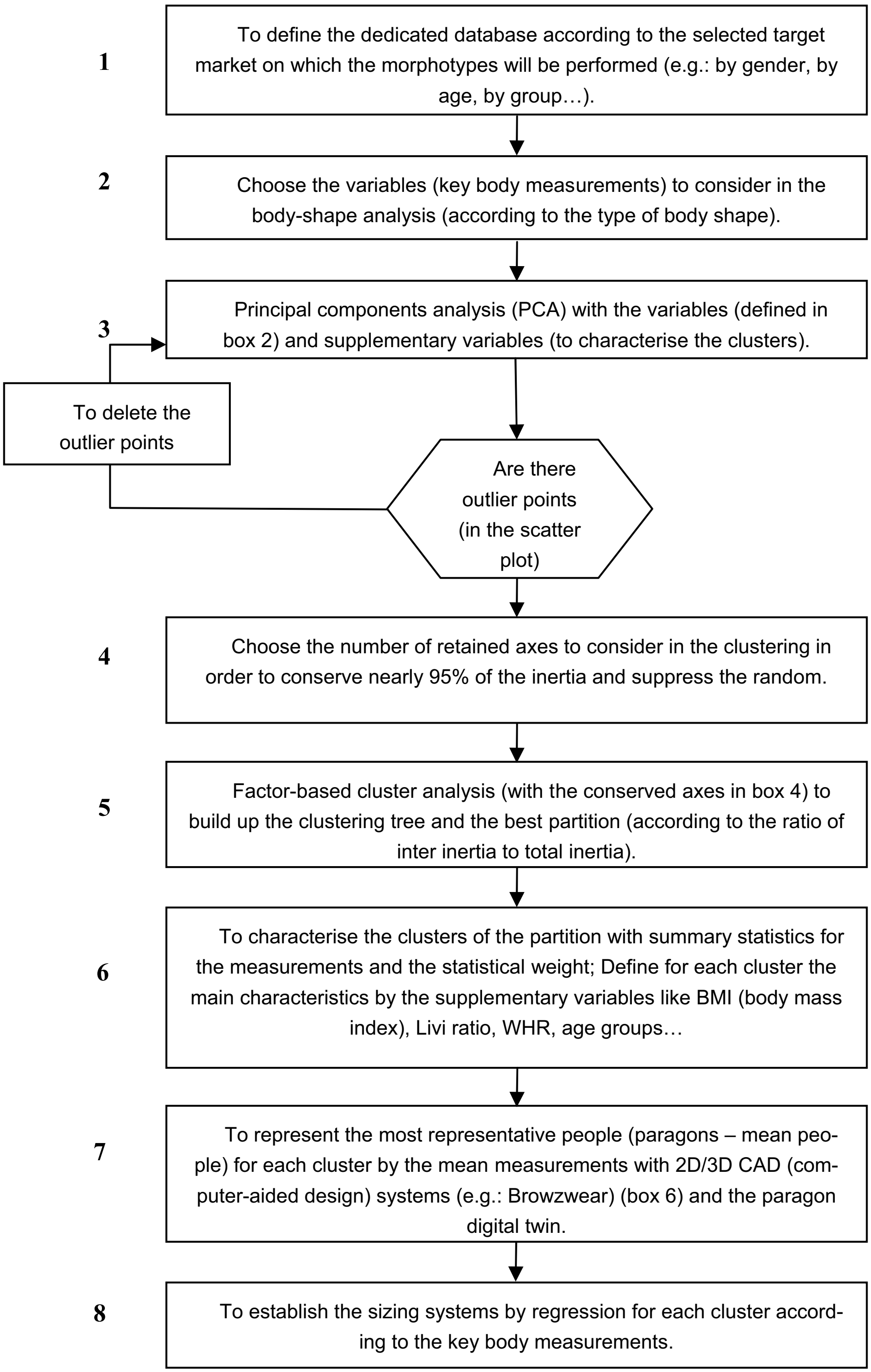

Fig. 4.8 Methodology flow chart to define morphotypes

4.2.2 Female Body-Shape Analysis

Before starting the process of body-shape analysis, it is important to define the body measurements used to classify the shapes. In this analysis, we considered 6 active variables[1] and 9 illustrative variables[2].

The active variables (see Fig. 4.9) are:

- the bust girth;
- the underbust girth;
- the waist girth;
- the abdomen girth (iliac crest);
- the high hip girth ASIS (anterior superior iliac spine);
- the hip girth.

The variables considered as illustrative are:

- the height;
- the weight,;
- the body mass index (BMI);
- the age;
- the waist-to-hip ratio (WHR);
- the bust-to-waist ratio (BWR);
- the waist–hip conformation;
- the bust–waist conformation;
- the chest–hip conformation.

For this study we have used data from the French Anthropometric database, containing a sample of 5,226 female subjects. After the clustering and its testing, the characterisation of the clusters was an important stage of the process: we have identified the main classes in the sample from the mean measurements and the visual analysis of the representative body scans for each cluster (see Fig. 4.10). Based on this analysis 7 body shapes were identified. The clusters have therefore been characterised as follows:

- Cluster 1: BOTTOM HOURGLASS;
- Cluster 2: TRAPEZOID;
- Cluster 3: SMALL SPOON;
- Cluster 4: HOURGLASS;
- Cluster 5: OVAL;
- Cluster 6: LARGE SPOON;
- Cluster 7: RECTANGLE.

The statistical distribution of the different morphotypes is depicted in Fig. 4.11.

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[1] Active variable: variable taken into account in the statistical calculations.

[2] Illustrative variable: variable that illustrates the statistical results and not taken into account in the calculations.

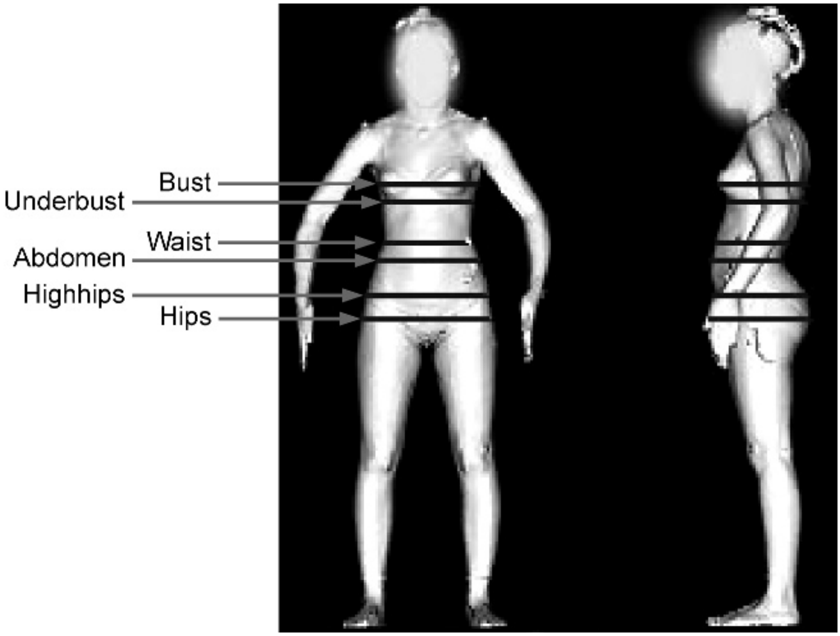

Fig. 4.9 Illustration of the positioning of the 6 basic body measurements considered for clustering purposes

On 5,226 female subjects, over 25.58% were designated as belonging to the bottom hourglass category, followed by the small spoon (23.88%), trapezoid (18.35%), hourglass (12.67%), large spoon (12.17%), rectangle (5.32%) and oval (2.03%).

The aim of the American national sizing survey funded by the U.S. Department of Commerce and industry partners conducted in the US between July 2002 to July 2003 was to gather "accurate and statistically significant U.S. population size and shape data" that could benefit the apparel, automotive, aerospace, commercial airlines, furniture, ergonomics and health-care industries. Data were collected from 12,000 subjects from all over the United States and representing six age groups ranging from 18–66+, four ethnic groups – non-Hispanic white, non-Hispanic black, Asian and Mexican Hispanic and non-Mexican Hispanic and four weight categories 'quite overweight', 'little overweight', 'underweight', and 'right weight', see (Devarajan and Istook, 2004).

In complement and for comparison, *see Table 4.3* for figures of the American study on body shaping.

The most represented shape is the bottom hourglass (25.6% for the French study and 40% for the American study, respectively). The distribution is, however, different for the next shapes. Indeed, the Spoon shape represents a share of 17.1% in the US against 36.1% for the French study (divided in two parts: the small spoon with 12.2% and the large spoon with 23.9%). The hourglass shape is more represented in the US: 21.6% against 12.7% in France. The rectangle shape shares 5.3% of the French female population against 15.8% for the US.

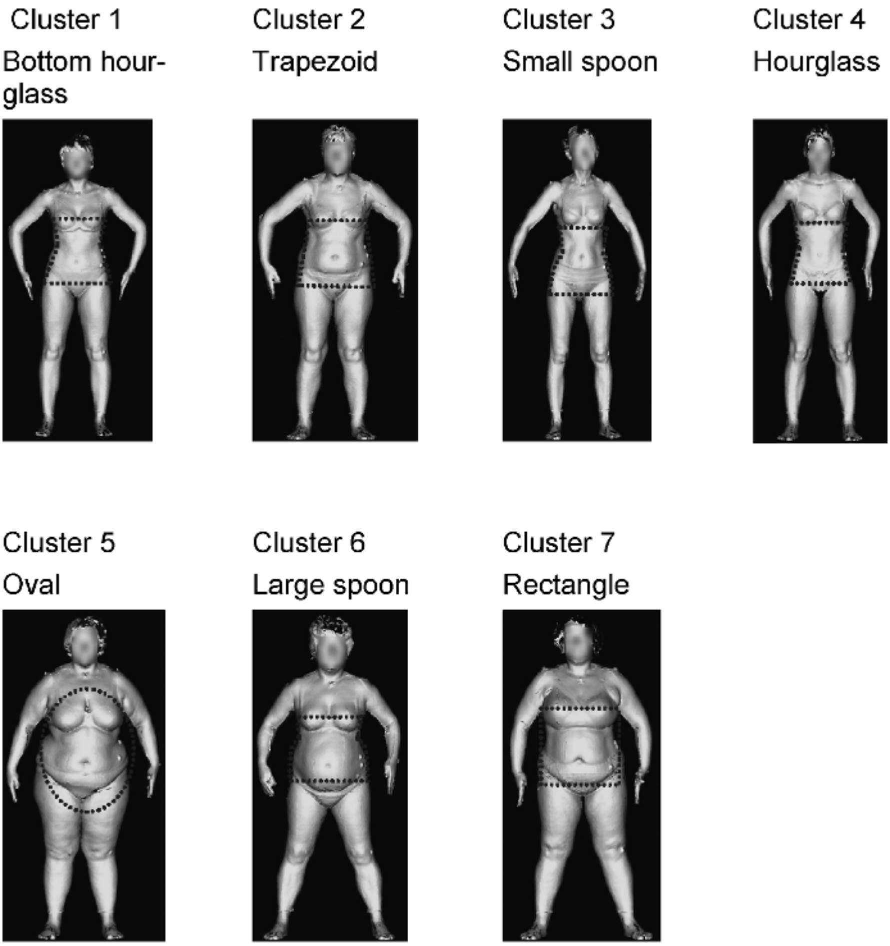

Fig. 4.10 Representative clusters (morphotypes) derived by clustering and subsequent visual analysis of the clusters for the female population

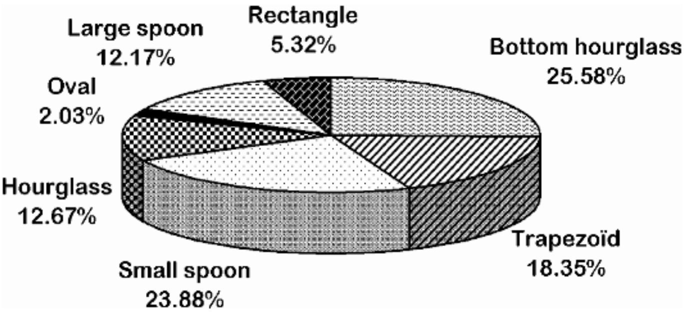

Fig. 4.11 Body-shape distribution (female population)

Table 4.3 Comparison between French and American studies

	French study	American study
Bottom Hourglass	25.58%	40%
Hourglass	12.67%	21.6%
Spoon	23.88% (small) 12.17% (large)	17.1%
Rectangle	5.32%	15.8%
Oval	2.03%	3.6%
Trapeze	18.35%	1.8%
Inverted trapeze	–	–
Diamond	–	–
Top hourglass	–	–

After the characterisation of the clusters by various figures, we can proceed with the characterisation of the people in each cluster. For this, the right way is to calculate the size charts for each cluster using linear regression models with 2 basic variables: height and chest girth. The linear regression model commonly used in the fashion industry is the following:

$$\text{Body measurement (Y)} = \alpha * \text{Height} + \beta * \text{Chest girth} + \lambda \tag{4.1}$$

Tables 4.4 and 4.5 are, respectively, an example of regression coefficients and an example of a size chart.

Table 4.4 Regression coefficients table

Measurements (Y)	α	β	λ
Weight	0.01651	0.83679	–1.99623
Head girth	0.03564	0.91231	1.58479
30 (7th cervical height)	0.64789	0.41578	–1.12050

Table 4.5 Size chart (final results)

	36			**38**		
Stature	156	165	174	156	165	174
Bust girth	80	81	81	84	85	85
Hip girth	89	91	93	92	93	95
Weight	45.8	49.7	54.2	50.3	54.1	57.7
Neck girth	30.2	30.5	30.2	31.2	31.2	31.3
Neck base girth	38.1	39.7	39.3	39	39.6	39.7
Bust width	35.6	35.3	36.2	36.8	37	36.9
Bustpoints breadth	16.2	16.4	16.4	17	17	17.2
Waist girth	63.9	64.1	64.4	67.9	67.9	67.5
Abdomen girth (iliac crest)	70.8	71.6	72.8	74.3	75.2	75.4
Back width	31.7	32.6	32.8	32.8	33.5	34.2
Wrist girth	15.4	15.3	15.6	15.7	15.6	15.9
Upper arm girth	24	23.6	24.3	25.4	25.1	24.9
7th cervical height	133	142	148	134	142	150
Inside leg length	69.4	75.8	80.6	70.5	75.6	81.1

4.2.3 Male Body-Shape Analysis

We applied the same methodology to define the representative body shapes for the French male population. Applying the same statistical methodology depicted in Fig. 4.1 on a sample of 4,037 male subjects, we have obtained the following 6 representative body shapes (morphotypes or clusters), which are illustrated in Fig. 4.5.

Cluster 1: Normal

The first cluster represents a set of 717 persons, that is to say 17.76% of the male population. The main characteristics within this group are:

- 92.74% have a normal weight (normal BMI – body mass index). The mean of the BMI is 20.75 kg/m^2.
- The 35 year-old group represents the majority (70.28%) of this population.
- The athletic conformation is the most represented with a high proportion of drop[3], drop 10 and drop 12 (with respectively 26.95%, 22.41% and 8.95%).
- The medium and the small are the most represented with 22.76% stemming from the small group against 45.54% for the medium group. The mean of the height within the group is 173.55 cm.
- The android shape is the most characteristic of this cluster with a proportion equal to 94.77%.

Cluster 2: Athletic

The cluster 2 represents the cluster with the highest count. Indeed, 29.68% of the male population belongs to this group, that is to say 1,198 persons. The main characteristics are:

- 89.50% have a normal weight, with a mean of the BMI of 23.30 kg/m^2 .
- The drop –8 and –10 are the most represented with respectively 28.93% and 16.56%.
- The most characteristic age group is 21–25 years old with 11.97% of the cluster and 26–35 years old with 29.35%. The 36–45 year-old group represents 22.7%. However this is not characteristic because the 36–45 years old are better represented compared to the 21–25 year-old group.
- 76.81% of them present an android shape.

Cluster 3: Light overweight

28.22% of the male population belongs to cluster 3, that is to say 1,139 individuals. The main characteristics observed in this group are:

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[3] DROP is defined as follows: for male: $D = \frac{1}{2} \times$ (waist girth – chest girth), for female: $D = \frac{1}{2} \times$ (hip girth – bust girth).

- 65.75% are overweight against 33.95% having normal weight.
- The 36-year olds and over constitute the majority with 24.84% of 36–45-year olds, 23.82% of 46–55-year olds and 25.92% of 56–70-year olds. The mean age within this cluster is 45.33 years old.
- 59.81% of them present a gynoid shape.
- Drop values of –6 and –4 are the most characteristic within this group with 30.20% and 22.69% presence, respectively. The observed conformation tends towards a squat shape.

Cluster 4: Squat

16.96% of the male population belongs to the cluster 4, that is to say 685 persons. The main characteristics are:

- 81.08% of them are overweight and 16.60% in obesity: indeed, the mean BMI is equal to 28.30 kg/m^2.
- 88.44% present a gynoid shape confirming the previous point.
- The stout conformation is the most characteristic: indeed, drop values of –4, –2 and 0 are present with respective % values of 30.73%, 17.23% and 6.83%.
- The 46-year olds are representative of this cluster: the 46–55-year olds are 29.51% against 33.72% for the 56-year olds and more.

Cluster 5: Potbellied

6.31% of the male population belongs to the cluster 5, that is to say 255 persons. The main characteristics are:

- 67.47% of them are considered obese. 22.58% are overweight, this figure is not characteristic of this cluster because they represent only 3.86% of the obese population. The mean BMI is about 31.98 kg/m^2.
- 97.24% present a gynoid shape and the stout conformation (drop values of –4, –2 and 0) is equal to 59.8% of this cluster.
- Men of 56 years and older are representative of this cluster (66.11%).
- The tall and the very tall represent 55.59% of the cluster: the mean height is about 178.16 cm.

Cluster 6: High potbellied

Cluster no 6 represents a set of 1.07% of the total sample, that is to say 43 persons. The main characteristics are:

- 100% of them present a gynoid shape (Shape being very much characteristic to obese people).
- The tall represent 54.15% of this cluster.
- The stout conformation is very much present (drop 0, drop –2 with a percentage equal to 51.81%).

The measurements within this cluster are very large concerning the obese persons: the mean of the main measurements are: 134 cm for the chest, 133.13 cm for the waist and 131.74 cm for the hip.

Summing up the body-shape analysis described above, we can define the following 6 main male morphotypes (see Fig. 4.13 for details on the distribution of the male population in these shapes).

- **Normal:** Male population with an athletic drop, a normal weight and a bust girth mean equal to 90.89 cm.
- **Athletic:** Male population with a drop equal to –8 or –10, a normal weight and a bust girth mean equal to 97.71 cm.
- **Light overweight:** Male population with a Drop equal to –4 or –6, an overweight and a bust girth mean equal to 103.96 cm.
- **Squat:** Male population with a corpulent conformation, in overweight or obesity and a bust girth equal to 110.55 cm.
- **Potbellied:** Male population with a corpulent conformation, in obesity and a bust girth mean equal to 119.71 cm.
- **High potbellied:** Male population with a drop equal to 0 or –2, in obesity and a bust girth mean equal to 134 cm.

The two most significant clusters are the athletic and the light overweight ones.

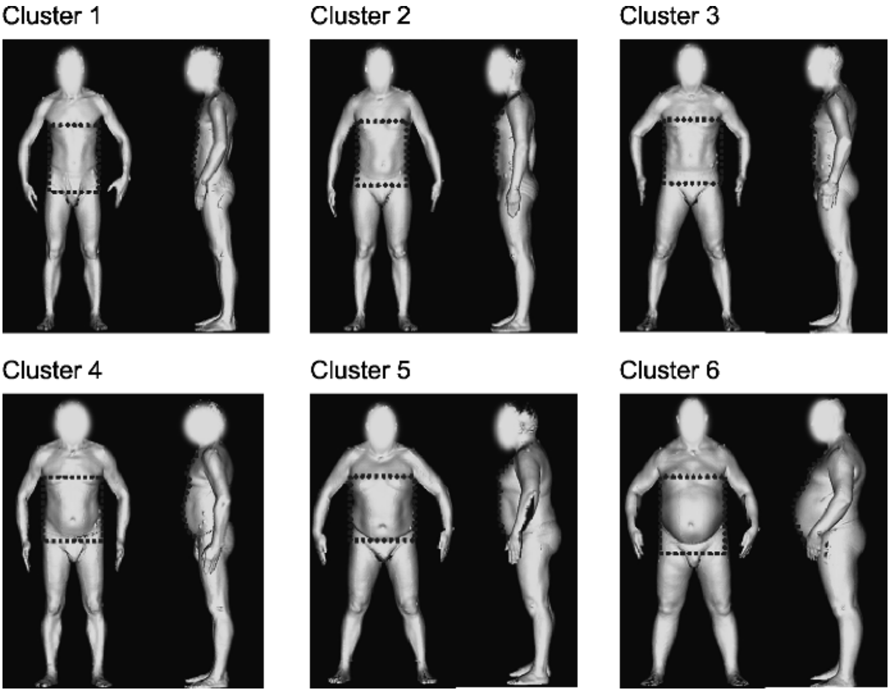
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6

Fig. 4.12 Representative male figures for each male cluster

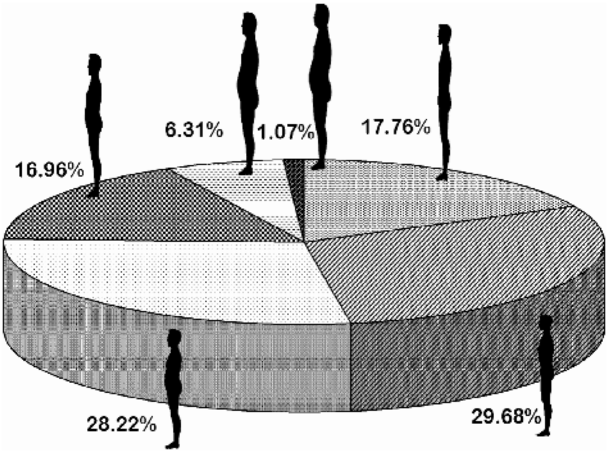

Fig. 4.13 Distribution of body shapes (Male population)

4.2.4 Conclusion

In today's apparel market, consumers desire to customise more and more the style, fit and fabric/colour of the garment they buy. Most of today's consumers require high-quality garments at a medium price and with the guarantee of good fit.

To satisfy these needs, it is important to know or to predict the body shape and the body measurements of consumers. The statistical calculation of body shapes based on comprehensive and recent 3D anthropometric data bases (France, United Kingdom, Germany, etc.) is a relevant key point to guarantee good results. The human-body models obtained thanks to the proposed statistical methodology have to be very similar to real existing morphotypes. In order to obtain realistic body shapes well representative of the domestic or European populations, it is important to have a large representative sample of the population. The body shapes could be calculated according to specific target markets (with criteria such as age group, social category …). We know that within the same consumer profile (age, social category …) there are several body shapes and automatically, for the same standard size, there is a fit issue.

The consequence of the current situation is that the consumers choose their size by default when trying garments on. The best solution is to design models according to the main body shapes that represent the target market of apparel manufacturers. During the prototype development and fit monitoring, the body shapes could be used in two ways:

- derivation of virtual mannequins connected with 2D/3D CAD systems (computer-aided design);
- usage of physical dummies to validate the prototype at the end of the design phase.

Physical dummies could also be used at production sites that are distributed worldwide. Thanks to this, the quality control of end-products is done with the same body-shape reference. Designing garments according to the right body shape is the guarantee of a good fit.

4.3 CVP – A Collaborative Virtual Prototyping Platform

George-Alexander Kartsounis, Florendia-Fourli Kartsouni, Zoi Lentziou

Abstract The CVP integrates all main LEAPFROG research results related to the new product development process in the form of a web platform enabling e-Collaboration between potential users of 3D design and virtual prototyping, such as product managers, designers, modelists and sales and marketing personnel in a scenario intended to speed up and enhance creativity and effectiveness. Physical sampling currently used in garment prototyping processes is replaced with shared visualisation of simulations and animations of virtually dressed humanoid mannequins. A significant challenge relates to the selection and definition of appropriate data-exchange mechanisms and technologies between remotely located knowledge sources and 3D design and simulation/animation systems, including data related to 3D garment design and derived 2D patterns, avatars representative of target consumer groups, fabric properties, prototype manufacturability and cost estimation web applications, etc. Data representation and data exchanges are based on web services and extensible markup language – xml.

4.3.1 Introduction

All manufacturing sectors face ever-growing demands for enlarged variety of products by customers whose requirements and tastes change rapidly, especially in the so-called lifestyle industries, where fashion is the pre-dominant element. Steady growth in product variety, averaging 1% per year has been recorded over the last 40 years (Klenow 2003). This imposes the need for ever-increasing frequencies of launching new designs. The current trend in successful clothing chains, for instance, is the design of new collections or the adaptation of existing designs to market response with collection update or adaptation frequencies exceeding 12 per year, as opposed to the traditional 4 seasons' collections. The acceleration in product variety has significant operational implications on all stages along the value-adding chain; however, the most critical implications concern the initial stages of new product development, namely design and prototyping (pre-production). Considering globalisation and delocalisation of operations along the chain, we can easily explain the additional complexity caused by communication and collaboration problems imposed on teams of individuals located in different places, with different roles, background and skills.

While the production of goods has moved offshore, some parts of the process, like styling and pattern design, remain in Europe or the US. Retaining the traditional competitive lead in design and style is a crucial challenge for the European fashion firms. This objective can serve both as a defensive barrier against lower quality and less aesthetically appealing products from low-wage countries in local markets, but also as a competitive advantage for penetration in the higher ends of the respective emerging markets.

The fractured nature of the production chain requires intense data flow and movement of raw materials over long distances. On the other hand, when teams of designers, product managers and engineers must collaborate on a development project they either have to fly to a meeting venue or cope with collaboration technologies that are quite limiting, such as video conferencing and web collaboration platforms that are of general purpose and do not specifically support a structured exchange of application specific data, such as designs, fabric properties, pattern files, morphotypes and body sizes, etc.

Product development represents a significant bottleneck in the clothing industry both in terms of time (up to 5 trial and error design-prototyping loops, lasting up to 12 weeks) and cost (up to 60% of the cost of a fashion product). Time postponement of design activities to reduce inventories (delaying commitment to any product attributes until real demand feedback is received) and the emerging mass-customisation model dictate a radically new approach, which will enable the drastic shortening of the ‘time to design’ (design, prototyping) including the complex interactions between geographically dispersed teams.

The development therefore of a platform linking 3D CAD to traditional 2D CAD and PDM (Product Data Management) systems, as well as providing on-line access to specialised services, such as a fabrics library, an on-line cost estimation facility, and a real-time interactive animation service (animated virtual try – on of different garment sizes on different body sizes and shapes), can significantly reduce ‘time to design’, reduce prototyping costs and provide an efficient e-collaboration environment for multiple actors involved in product development. This is the objective of the collaborative virtual prototyping platform that will be detailed in the following sections.

4.3.2 The New Design Process Flow

4.3.2.1 Current Industrial Prototyping Practices and Processes

LEAPFROG industrial partner La Redoute provided a concise example of current processes in garment design and production, used for the development of the new collections for their own brand, involving the collaboration of renowned stylists (e.g. Jean-Paul Gauthier).

Fig. 4.14 The main steps in the product development process of La Redoute

The design steps as depicted in Fig. 4.14 are those numbered from 1 to 5, namely:

- **Step 1: Idea conception:** The product-development process is initiated by the product manager who conceives the general idea of the new collection. It is then the responsibility of the designer/s to investigate possible options for parameters such as shape, colours and fabrics, decide on these and create the first draft sketches. Sometimes, the product manager and the designer are the same person in cases where, for example, a designer is appointed with full responsibility for the creation of a collection. (Estimated time for the idea to be complete = 1 week.)
- **Step 2: Technical development (2D patterns, technical details):** The modelist works on the technical interpretation of the initial idea by specifying technical details and producing 2D patterns (when necessary). Sometimes, the two tasks (technical specification, pattern making) are performed by two separate modelists, respectively. (Estimated time for the technical design to be completed = 2 weeks.)
- **Steps 3 and 4: Initial sample production and quality control:** The technical design is sent to the manufacturer[4] where a first sample of the product is developed. The quality department applies quality tests to the fabric as well as measurements control and fit evaluation. The results of the tests as well as the samples are passed on to the product manager who does his/her own evaluation and suggests any necessary alterations in collaboration with the modelist/s and the designer/s. (Estimated time = 4 weeks.)

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[4] In some cases, suitable manufacturers are identified by agents, which receive the technical design and examine available offers for the fabrics and the production of the garment.

- **Step 5: Sample approval:** In the case that the initial sample satisfies the predefined quality standards, then the approval for production is given by the product manager. Otherwise any required alterations are applied to the technical design by the modelist and a revised sample is ordered. When this sample is received, Step 4 in the process is repeated. This recursive process continues until a sample is approved. (Estimated time = 2 weeks or more depending on the number of samples required, usually up to four samples are created.)

4.3.2.2 The New Collaborative Design Process Enabled by Virtual Prototyping

- **Step 1: Project initiation:** The product development process is initiated by the product manager who conceives the general idea of the product (collection). He/she initiates a project, which includes the initiation of a collection and the arrangement of *virtual meetings*. A new project is defined by the identification of the actors that will work on a collection (also involving roles that are being assigned to each of them). A project consists of a set of user-defined entities, such as:

  1. Garment types (e.g. trousers, jackets, knitwear, etc.).
  2. A set of morphotypes representative of the customer population targeted by the collection (such as e.g. French ladies aged 40-50 years). These morphotypes are derived according to the clustering methodology described in Sect. 4.2.
  3. The list of fabrics to be used. Technical data for these fabrics can either be derived from the local CVP fabrics repository or from the on-line linked fabrics library (Kartsounis 2006).
  4. Cost and pricing information that the company is willing to assign per garment.

According to the design roles assigned, each collaborating designer obtains access to the information pertaining to his/her design items.

- **Step 2: 3D design and simulation:** Each collaborating designer can access the CVP at any time, download the necessary data, including 3D garment blocks (set of 2D patterns required to create and simulate a standard garment for each garment type), fabric parameters, and body measurements of representative morphotypes to be used for virtually trying on his/her new designs. He/ she creates a new garment using the 3D Design tool (see Sect. 4.1). When the new garment is finished, the designer uploads a file (including all the necessary information about the design) on the CVP. The garment is already in a 3D simulated form so a first evaluation can be easily performed by the product manager, or other actors accessing the showroom area of the CVP (see Sect. 4.3.4 below).

- **Step 3: Design evaluation:** There are three different options available to any authorised user to evaluate a new design:
  - **Real-time simulation and animation:** A remotely located 3D real-time animation web-delivered service linked to the CVP (real-time simulation and animation on representative morphotypes), enables the creation of a preview of the garment on animated mannequins of varying sizes. This process is normally quite fast (although not necessarily in 'real-time'), since all the necessary information required to simulate and animate a garment are readily available on the platform.
  - **Comfort and fit evaluation:** Fit and comfort evaluation can be performed at the designer's site using the 3D CAD system.
  - **Manufacturability prediction and cost estimation:** The designer and/or any other actor authorised by the product manager can benefit from the use of an on-line service, which can predict the behaviour of the selected fabric/s under different manufacturing processes. This service is linked to the Cost Estimation service, which can provide a fast estimation of the cost of a new model, depending on the overhead induced by necessary measures needed to overcome manufacturability problems. This service can provide marketing, purchase, engineering and quality departments with sensitive information that they will have to address in a collaborative process in order to reach a consensus taking into consideration the requirements in terms of quality and price. Based on the results of the evaluation methods, a designer or a project manager may decide to approve or reject a design.
- **Step 4: Derivation of 2D patterns:** Once a design has been approved, the 2D patterns that are needed for its construction can be uploaded to a conventional 2D CAD/PDM system linked to the CVP. The current format for transferring pattern data is the AAMA, dxf-based standard (Chang 2000), however in the near future the more recent ASTM standard (Hwang Shin 2006) will be adopted. Work in this area has been based on a review of the prevailing standards for 2D CAD data exchange in the industry, results of previous standardisation activities (Kartsounis 2003), as well as recent relevant publications (Hwang Shin 2006).

4.3.3 CVP Architecture

The CVP databases have been developed in Oracle 8.1.7 Enterprise, while the business layer is built in .Net 2 (Cook 2005). The web services are built for use with SOAP 1.1 and SOAP 1.2 (simple object access protocol), a lightweight XML-based messaging protocol used to encode the information in Web service request and response messages before sending them over a network (Gudgin 2007). Any client application that can make use of SOAP web services can connect and make use of internal CVP databases, such as the morphotypes library.

Technology wise .net soap web services can be consumed by Java, a programming language expressly designed for use in the distributed environment of the Internet, .Net and many more without difficulty. Figure 4.15 shows the main components of the CVP, as well as their links to external web-delivered services, such as RTAnim standing for real-time simulation and animation, developed by *Miralab University of Geneva*, D3D-2D Flat, which is the 3D CAD system based on the VStitcher Direct 3D version developed by Browzwear see Sect. 4.1), Fab-Model, the on-line fabrics library, as well as MCA-MCE, the manufacturability and cost estimation on-line services developed by the Institut Francais Textile et Habillement (IFTH). This diagram provides an overview of the CVP on-line environment and does not detail the components of the CVP itself, namely the local repositories, the virtual meetings and the showroom that are described in Sect. 4.3.4.

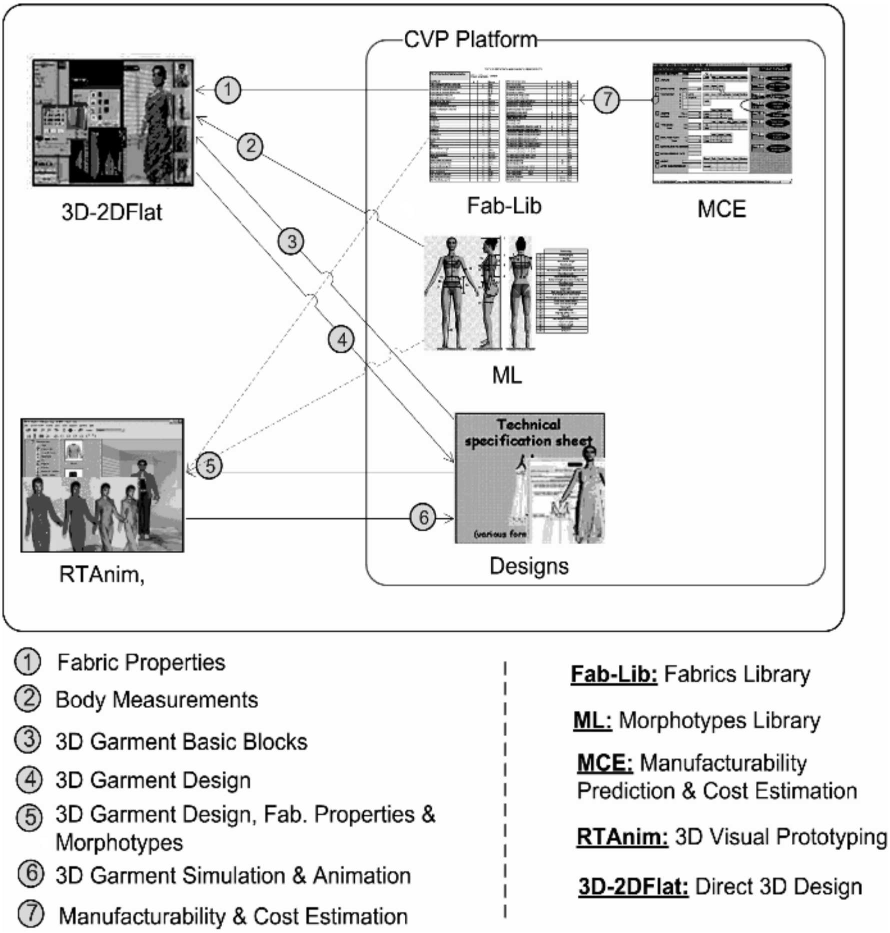


Fig. 4.15 Block diagram showing the main on-line components of the CVP and their links

4.3.3.1 Security, Access, Permissions, Roles

Specific security and trust functionalities have been incorporated in the platform and will be developed further during the commercial exploitation of the platform. The platform is intended both as a global service accessible by companies subscribing either as members or as temporary users, or as an internal enterprise platform for sole use by one company. Security issues and the protection of IPR (intellectual property rights), both at a company level or for the interests of individual designers, is of paramount importance for the successful exploitation of the platform. The following is an indicative list of measures already incorporated or intended for future implementation:

- Authentication of users to avoid unauthorised access to the platform: In order to acquire access to the CVP platform, the users will have to follow a registration process.
- Access and privileges schemes to define different security levels, depending on user, system or area of the platform. Different users may have different access rights to designs and other information such as fabrics and data from the morphotypes library. For this reason the platform administrator can create ‘roles’ and ‘access’ schemes that will specify the purpose and privileges of each actor participating in the CVP.
- A clearly defined, consistent set of policies and procedures will be established during the commercialisation phase of the platform. This set of policies will include IPR specifications and rules, as well as the definition of trust and liability issues. Each user of the platform will be required to agree to the defined policies in order to complete his/her registration to the platform.
- Specific technical security measures such as provisions for secure data transmissions over internal or external communication channels, data-integrity mechanisms, server security measures, etc., will also be established.

4.3.3.2 Data Integrity (Versioning System)

During the life cycle of a design (from concept to production) a team of people will work on it (designers, modelists, etc.). In order to keep track of the various changes to a design, a versioning system is implemented as an integral part of the CVP platform. The versioning system is able to track the changes to a design recording:

- the user that made the change;
- the time that the change occurred;
- any comments that any user may want to make related to his/her or other users changes to the design.

In order to render access to the correct version of a design, designs will be presented in an order depending on the date that they were modified. In addition, the user will be able to request to view designs of a particular date (or a range of dates).

4.3.4 CVP Functionality and User Interface

The CVP offers three main functionalities that are accessible to the different actors, according to their roles and rights:

1. **Initiation of a collection:** This functionality is described in Sect. 4.3.2.1 above (step 1) and is accessible solely by the product manager (PM).
2. **Virtual meetings:** Collaboration, being the main purpose of the CVP platform, requires the facilitation of communication between the various collaborating actors. On-line communication is enabled in the form of structured sessions, called virtual meetings. Specific meeting sessions are initiated by the PM, whereby all the design collaborating actors can participate from remote locations. They are able to communicate through a messaging system and can suggest modifications and comments, whereas at the same time the main conclusions of the discussions are recorded and stored as records in the CVP in the form of short minutes of the meeting. During virtual meetings all participants can access visual information, such as images and flash animations and comment on others' suggestions and proposed designs. The design items being discussed are automatically displayed and highlighted on the screen. Remote designers can effect suggested alterations during the session and upload them to the showroom area (see below) for other participants to view and comment.
3. **Showroom:** The platform contains an area, which is called 'showroom' and where all current versions of garments are hosted and can be viewed. The showroom has also the additional functionality to display images and flash animations of a complete outfit including the garment that has been selected. Apart from the visual representation files there is also a technical file attached to each garment, which includes all constituent pattern pieces of the design that other designers can download locally and make modifications. The usage of such an area is intended for: (a) marketing personnel to be able to show the progress of a garment or of a whole collection to an interested customer and also to be able to post some comments next to the file, (b) designers, accessing existing design versions in order to make modifications. The developed new file will be posted back to the platform, as a different version of the same garment. A suitable versioning system is enabled, each time a new version is created. All versions can be displayed along with their attached historic data, comments from others, etc.

Figure 4.16 summarises the steps that are being followed by the main actors, i.e. the project manager and the designers.

When the user clicks on the 'showroom' button, he/she gets a list of available collections, possibly from different companies subscribed to the platform. As soon as she chooses one specific collection, she can view images of outfits including collection items along with associated flash animations. By clicking on any outfit she can see images of the garment items this outfit consists of. Alternatively she can view images of each type of garment that has been created within the collection as well as flash animations of each garment. Figure 4.17 illustrates the latter possibility.

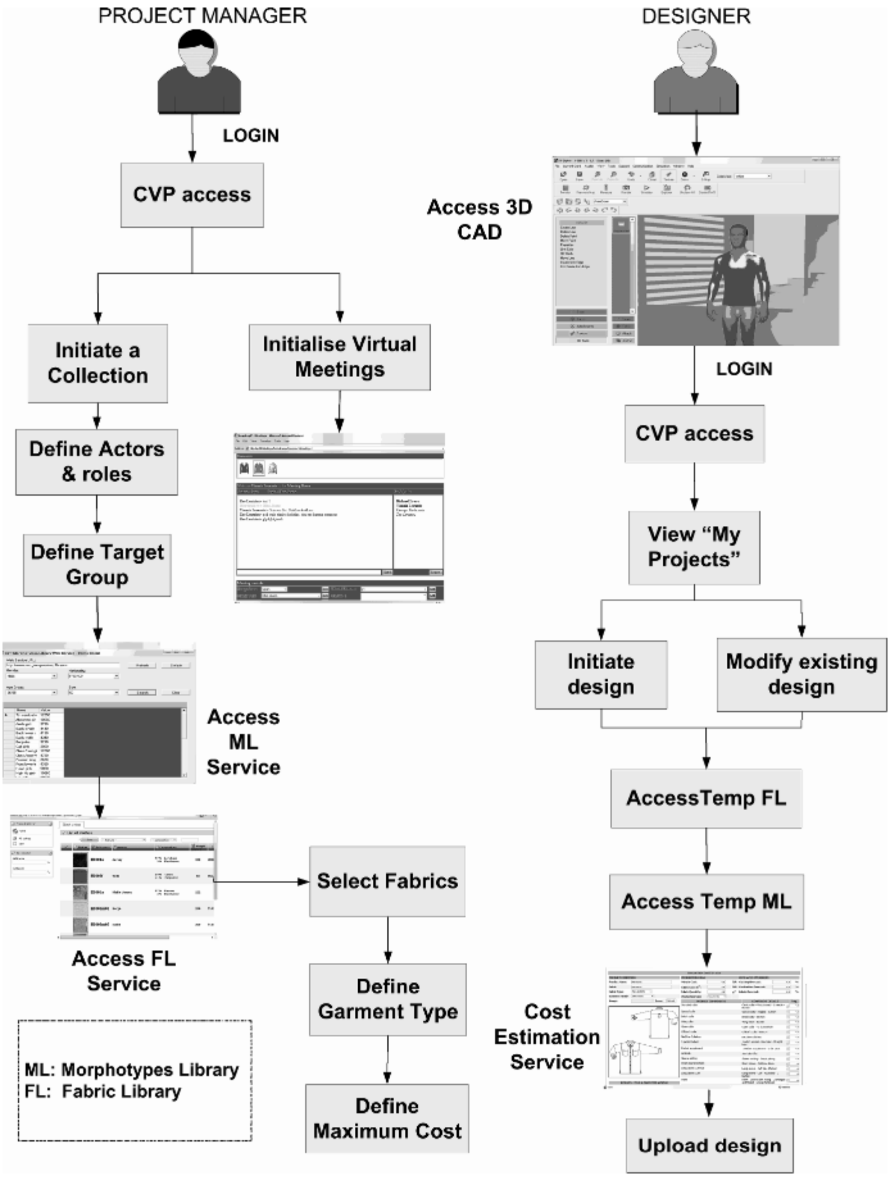


Fig. 4.16 Typical workflows assigned to the main CVP actors, i.e. the product manager and the designer(s). ML: morphotypes library, FL: fabrics library, VStitcher a typical 3D CAD system by Browzwear

Finally, when the user clicks on the 'meetings' button, he is directed to a dedicated chat area, where he can discuss with other involved actors. Meetings are normally scheduled by the PM, who has the ability to change the topics of a predefined agenda or to insert a new topic. He can also edit short conclusions per

Fig. 4.17 Typical screenshot from the Showroom Area. The user can visualise a static 3D simulation that can be rotated, zoomed, etc., as well as a virtual catwalk of the same garment following a short time it takes to connect to the Miralab (University of Geneva) real-time animation service

topic. These will be recorded and attached to the specific collection items under discussion. All participants thus have the ability to see images and flash animations of the garments that are being discussed during a virtual meeting.

4.3.5 Conclusions

A web-enabled platform has been developed for e-collaboration among remotely located actors involved in the critical stage of product development in the fashion industry. It enables the drastic reduction of the ‘time to design’ as well as the involved costs, since it eliminates the need for quick physical prototyping and testing on human mannequins by seamlessly linking on-line heterogeneous virtual prototyping tools (such as 3D CAD systems, 2D CAD and PDM systems, simulation and animated virtual try on services), as well as web-delivered knowledge sources, such as libraries of fabric properties, manufacturability and cost estimation applications. The most significant challenges related to the selection of appropriate data exchange mechanisms and technologies (based on web-service technology and xml), as well as the adoption of a usage scenario tailored to the needs of dispersed design teams. At the time of editing this section the platform was undergoing its final development, testing and evaluation stages and initial plans for its commercial exploitation were considered.

4.4 A New Method of Estimating Fabric Simulation Parameters Based on Automatic Image Analysis

Harris Georgiou, George-Alexander Kartsounis, Martin Rupp

Abstract This section proposes a new method for fast and efficient estimation of simulation parameters, currently being identified by long and expensive measuring techniques (Kawabata, FAST). The task aimed at the automatic comparison of the drape of a sample of an unknown fabric with that of the drape of known fabrics in a fabrics library, based on image analysis of their corresponding projections when lying on a standard circular base (extension of the Cusic drape meter). The original idea was that the combination of the simple drape meter apparatus with automatic image analysis and state-of-the-art statistical learning algorithms could lead to the development of an innovative technique for the fast evaluation of the simulation parameters for any unknown fabric leading to faster and easier adoption of virtual prototyping by the industry.

4.4.1 Introduction

The mechanical parameters that are used for the simulation of fabric drape over the bodies of virtual mannequins for virtual prototyping are currently measured by standard laboratory equipment (e.g. Fast, Kawabata), a process that is tedious and expensive. Previous work has established the significance of certain mechanical parameters of the fabric (such as weight, thickness, shear rigidity, bending rigidity and elasticity) to the way a garment falls over the body (Frydrych et al. 2000). Simple physical models for the analytic modelling of the drape shape have also been reported (Rödel et al. 1998). Characteristics such as the drape coefficient can be obtained from the vertical projection of a hanging fabric sample. The Cusic drape coefficient (British Standards 1973) that is a simple metric based on the area of the vertical projection of the draping sample fabric, the area of the round sample holder, and the area of the sample, has been established as a stable and reproducible measure of fabric drape. However, the drape coefficient alone cannot be used for the simulation of garment drape over the bodies of virtual mannequins. For this purpose we need the actual values of the mechanical parameters.

Extensions of the conventional Cusic apparatus involving image analysis for the derivation of additional features of the drape projection image (e.g. the number of folds, characteristics of folds, etc.) have also been reported recently (Park et al. 2004), (Mizutani et al. 2005). These can result in more detailed description of the drape, but still they cannot yield estimates of the actual mechanical parameters. Based on those findings, researchers in Hohenstein Institute have developed a simplified, and fast technique for the characterisation of fabrics in terms of their mechanical properties affecting the drape of the garment. In cooperation with other LEAPFROG partners they have developed a fabrics library including key mechanical parameters of a number of reference fabrics, accompanied by representative images of the projections of fabric samples draped over a circular support. This method is also based on the conventional Cusic drape meter (Fig. 4.18). However the important difference in this approach is that now the objective is to estimate for each new fabric the actual mechanical simulation parameters (and not the drape coefficient) by a simple, fast and entirely automatic technique.

The resulting manually derived contours of the drape projections were subjectively classified into 23 shape categories by an experienced human observer. One of the important findings of the initial work by Hohenstein that was based on the subjective visual comparison of drape images, was that the determination of concrete correlations between fall and draping of garments and their tracing back to physical parameters by using simple features, such as the number of folds as well as subjective visual classification of the drape image shapes was more complex than expected. The results showed that the draping behaviour of single and multi-layered material of fabrics could not be modelled reliably by considering a few isolated features of the drape boundary (LEAPFROG 2006). These simple features showed non-repeatability, i.e. they varied between different instances of the draping of the same fabric under different conditions in a random manner. The first results of this manual observation resulted in an ad hoc subjective classification of the obtained drape boundaries in a number of classes that proved non-representative of the sample of known fabrics.

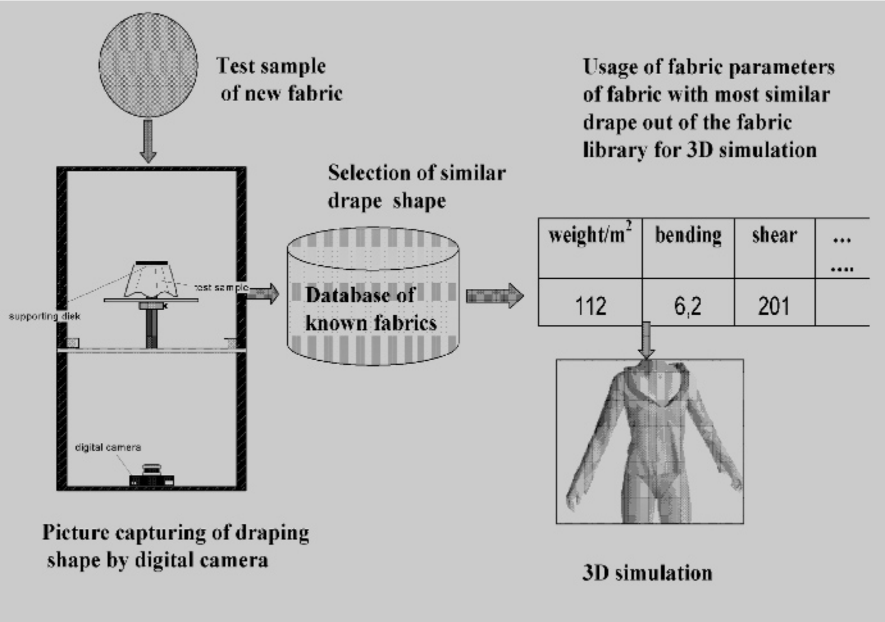


Fig. 4.18 Conceptual diagram illustrating the suggested method for the estimation of simulation parameters

A need therefore arose to model the drape boundary by a more information-rich statistical representation that could only be obtained by a statistically based objective evaluation of a large number of instance invariant features obtained by automatic image analysis and statistical inference (LEAPFROG 2007).

4.4.2 Materials and Methods

The task of drape image analysis, recognition and categorisation consists of several consecutive procedures that are required to transform the initial colour image to a set of well-defined invariant shape descriptors or ‘signature’ for every drape category.

The overall process was organised into three discrete phases:

- Model assessment: Design of models, datasets and pre-processing stages for the drape images.
- Pre-processing: Processing of the complete set of the drape images and acquisition of the selected shape descriptors.
- Categorisation-prediction: Design and implementation of predictive models regarding the correct recognition of some basic properties and/or physical parameters of the fabrics.

4.4.2.1 Phase-1: Model Assessment

The initial database consisted of 90 fabric drape samples, photographed at five realisations each, resulting in a total of 450 sample fabric drape images. The samples were organised into three categories according to their layered characteristics, namely: ML for multi-layered, SL for single-layered and Q for others. Since the purpose of this work was to establish a basic methodology for automatic drape image analysis, only the single-layered fabric set was used, i.e. the SL. This image set was used as an image-related representation of the FL database (LEAPFROG 2006), along with the standard measurements, physical data and category memberships already contained in the database. Each drape image was considered as an autonomous data sample, i.e. not explicitly linked to the other four realisations (photographs) of the same fabric sample. This assertion is valid since the shape descriptors should be invariant to different realisations of the same drape sample, i.e. they should be able to closely match images (drape shapes) that correspond to the same drape sample (same fabric). The issue of statistical dependence and possible clustering of the resulting shape data was addressed by employing the largest dataset available (SL) and using extensive randomisation procedures during training (see below).

The first phase of this work was focused on the design and optimisation of the ‘acquisition’ procedures of drape shape properties, since these morphological characteristics are implicitly related to the physical properties of the fabric itself

(Park et al. 2004, Pandurangan et al. 2004). Specifically, the assessment and evaluation of various models was organised into two major areas of interest:

1. pre-processing filters for image restoration;
2. geometric correction for camera lens effects.

The standard image pre-processing addresses typical image-acquisition problems, including noise, motion blurring, non-uniformities of field (gain profile, flat-field correction), camera deficiencies (bad pixels), etc. These filters can be implemented as spatial convolution kernels or spectral filters, according to their desired response functions. In this study, the issues that were considered were only those related to noise and other spatial artifacts, since the geometry, equipment and experimental setup was fixed for the entire set of acquired images.

Geometric correction methods address the problems related to lens deficiencies and non-linearities, which are typically the results of using real cameras that do not correspond to the ‘perfect’ pinhole camera model. In practice, the image is deformed geometrically through a set of well-defined transformations, including pincushion, barrel and perspective distortions. These transformations can be ‘inversed’ by designing approximate analytical models (Gonzalez and Woods 2006). In this study, the single most relevant issue identified was the barrel distortion, typical to all the commercial CCD-based digital cameras (Pers and Kovacic 2002). Hence, an analytical model was employed for implementing a geometric correction filter, after the drape shape boundary was acquired.

4.4.2.2 Phase-2: Pre-Processing

The model assessment phase of this work resulted in the design specifications of the optimised ‘pipeline’ for processing the raw drape images and creation of a robust representation of the drape boundary shape, subject to further analysis in subsequent stages.

Two protocols were implemented and applied on the entire drape image database. Specifically, a set of sub-processes were identified for each primary stage (pre-processing filters, geometric corrections) according to standard image processing techniques (Gonzalez and Woods 2006).

For the pre-processing filters, the procedure included several ‘pipelined’ spatial filters for region-based and morphological transformations, applied on each drape image separately. The exact sequencing and parameters of these sub-processes were identified and optimised after extensive experimentation, as follows:

1. conversion of 24-bit RBG image to 8-bit grayscale;
2. resizing/rescaling of the image;
3. cropping of image, extraction of region-of-interest (ROI);
4. histogram normalisation (contrast enhancement);
5. identification of object center;
6. optimised histogram thresholding (segmentation);

7. edge detection and tracing of drape boundary;
8. speckle removal (erosion filtering);
9. non-continuities removal (dilation filtering);
10. skeletonisation (edge thinning).

The images were converted to grayscale (from RGB) in order to render them compatible with standard morphological transformations (‘operators’). Rescaling ensured that all the images were processed at the same physical spatial resolution (corresponding to the 250 mm of the photographed plane). The downscale factor chosen was roughly ×0.5 per dimension, resulting in a spatial resolution of 5 pixels per mm (instead of 10 pixels per mm originally). Both these procedures contributed to a × 10 to × 12 speed up of the overall process, since the original drape image was reduced to 1/4 of its original size and 1/3 of its original colour representation depth, with no decrease in the information content of the significant morphological properties of the drape boundary itself.

The region-of-interest (ROI) was defined as the minimum rectangular box containing the complete drape object. This approach was necessary in order to isolate the most relevant portion of the drape image before any further processing, especially the contrast enhancement step that follows. The center of the drape object was identified both experimentally, using fixed measurements on the image and the equipment setup itself, as well as through an adaptive imaging technique, using the Radon transformations for multiple 1D projections and the identification of mass center (Gonzalez and Woods 2006). Both approaches resulted in the correct identification of the center of the drape object with typical error of 1 mm or less, which was verified as acceptable for this particular study.

Using the properties of the grayscale histogram of the ROI, as well as the prior identification of the center of the drape object, an optimised histogram thresholding technique was employed to segment the drape object from its background with minimum loss of drape boundary pixels and minimum number of noise artifacts. The thresholded drape object was subsequently converted to a contour image using a standard edge detection filter (Sobel), which practically introduced the first rough version of the signal of interest, i.e. the drape boundary.

Several morphological operators were used for correcting and enhancing the contour signal before extracting any shape features. First, an erosion step was employed for speckle removal, as the initial boundary signal was saturated with spatial noise. Second, a dilation step was employed for restoring any boundary pixels that were removed during the erosion step, producing discontinuities on the contour signal. This pair of subsequent morphological operations (erosion-dilation) is called the ‘closing’ process and is typical of contour-related operations in image processing. The contour signal was further enhanced by employing a skeletonisation filter for edge thinning.

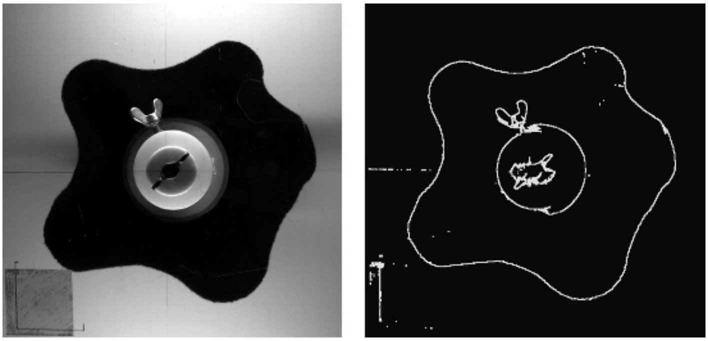
The boundary itself was extracted by a separate contour-tracing algorithm that resulted in the creation of a set of ‘boundary’ pixels, i.e. a complete 1D representation of the shape of the drape object. This 1D representation of the drape shape is in fact a parametric function in a 2D space, which means that it can be transformed into Cartesian, polar or complex representation at any time. The extracted shape was corrected for geometric (lens) distortions using a custom barrel distortion correction model (Pers and Kovacic 2002). Although this type of distortion is the most prevalent factor in CCD-based commercial cameras, the maximum spatial correction that was measured along radial axes was about 3 pixels or less, i.e. 740 nm at most for the re-scaled version of the drape images, which is still considered too small with respect to its influence on the major shape features of the drape object in this study.

The resulting shape signal was subsequently interpolated in complex form, using standard bi-cubic spline interpolation. This spline representation was essential in order to acquire the drape boundary in analytical form, which is necessary for many derivative-based shape features in subsequent phases. The spline representation was also used for re-sampling and registration of a fixed number of reference points for the complete shape signal (256 points) for all drape images, regardless of the length or any remaining noise artifacts of the raw boundary signal itself.

The final result of this second phase of processing was a fixed set of reference points from the drape boundary, referring to the corresponding physical model of the fabric drape itself (analytical spline model, instead of the sequence of pixels).

Figure 4.19a presents the original drape image (photograph). Figure 4.19b illustrates the detected drape boundary, which was subsequently interpolated in complex form, after applying all the steps of image pre-processing and registration described above.

Due to some practical problems resulting in deficiencies in the acquisition process of the drape images, the SL set was not exploited to its full extend. Specifically, 140 out of 335 drape images in the SL set have been excluded from all the subsequent phases of this study, due to improper colour contrast (fabric/background), as well as non-correctable artifacts from the supporting mechanisms of the experimental setup or low-quality image segmentation. All these apparatus-design-related problems have been corrected in the final version of the system.



(a) (b)

Fig. 4.19 (a) Original drape image, (b) Detected drape boundary (outer boundary) following image pre-processing

The final set contained 195 drape images, which was considered adequate for the purposes of this study, in terms of size and unbiased statistical distribution of various types of drape shapes.

4.4.2.3 Phase-3: Categorisation-Prediction

The categorisation-prediction phase of this work resulted in the design, implementation and testing of various classification and regression models, based on a wide set of shape features that were used as shape descriptors or 'signatures' of the drape boundary.

First, the registered spline function of the drape boundary was used to calculate the same spatial signal in multiple representations, specifically in Cartesian, polar and complex forms. Although most shape features were defined based on the radial-angular representation of the boundary, these multiple representations were necessary to serve as the base data for some of the shape descriptors (e.g. spectral analysis). In all cases, the base signals were normalised before any further processing, to ensure invariance against possible re-scaling of the drape database images.

The set of shape descriptor candidates included a total of 129 shape feature functions, selected from typical contour-based, region-based, spectral or higher-order curve functions. In most cases, each shape feature was encoded as an 8-value vector by employing eight standard statistical measures, presented in Table 4.6. The complete list of all the 129 shape features employed in this study is presented in Table 4.7.

The new dataset of composite shape features vectors were subsequently used as the base data for developing classification and regression models. These models were employed as the final stage of the overall drape image analysis system, using content-related characteristics of the drape shape to predict its corresponding physical (fabric) properties or classify it into one of the available pre-defined categories of fabrics with known properties.

The two primary models selected for this task were: (a) classification and regression trees (CART) and (b) weighted k-nearest neighbours (w/ knn) (Theo-

Table 4.6 Standard statistics used to encode each shape feature function as a single 8-value vector

Standard statistical measures for features
mn: minimum value of input signal
mx: maximum value of input signal
rng: range of values of input signal
avg: mean value of input signal
sdv: stdev value of input signal
skw: skewness value of input signal
kur: kurtosis value of input signal
ent: entropy value of input signal

doridis and Koutroumbas 2006). These two models were used for designing classification and regression predictors. Additional models were used for specific data analysis tasks, such as T-test, F-test and MANOVA (Cooley and Lohnes 1971) for statistical significance analysis and feature rankings, as well as the k-means algorithm for data clustering (Theodoridis and Koutroumbas 2006).

Using the results from previous studies (LEAPFROG 2006), the first experiments included direct classification tests against a set of *23 subjectively derived drape shape categories* (see Sect. 4.4.1). This scheme was repeated with k-means clustering for re-distributing the drape samples into 15 to 25 new clusters. These preliminary results confirmed the general feasibility of this shape-based drape analysis approach; however, it verified that classification and/or clustering of the drape samples against the subjectively derived class labels was inefficient in terms of accuracy (success rates). This result re-asserted the initial finding from Hohenstein, namely that the draping behaviour of fabrics could not be modelled reliably by considering a few isolated features of the drape boundary, as well as subjective classification by a human observer (see Sect. 4.4.1).

Table 4.7 Standard statistics used to encode each shape feature function as a single 8-value vector. Value at offset 01 is reserved for sample reference (imageID)

Composite shape features vector with all the calculated values
02..09: base stats for C data series
10..17: base stats for X data series
18..25: base stats for Y data series
26..33: base stats for R data series
34..41: base stats for half-spectrum of C data series
42..44: exp. regr.func parameters of half-spectrum of C
45..52: base stats for half-spectrum of R data series
53..55: exp.regr.func parameters of half-spectrum of R
56..63: base stats for Fourier descriptor series of (R,A)
64..66: exp.regr.func parameters of half-spectrum of FD
67..74: base stats for R-based curvature data series
75..82: base stats for XY-based curvature data series
83: number of zero-crossings against mean value in R
84..91: base stats for 1st derivatives of R at zero-crossings
92..100: base stats for weights (sin(AoA)) of R at zero-crossings
101: number of signal peaks (inward/outward folds) in R
102..109: base stats for R at signal peak points (only)
110..117: base stats for angular distribution of signal peaks
118..125: base stats for inertia moments of signal at peak-point axes
126: min/max ratio of inertia moments of signal at peak-point axes
127: total length (perimeter) of signal curve
128: total area (enclosed) of signal curve
129: area ratio parameter of signal curve
130: circularity parameter of signal curve

Based on these preliminary results, the basic approach was modified appropriately in order to overcome the ambiguous subjective drape class labels. Specifically, the target parameters to be estimated by the predictor were now *the physical parameters themselves*, instead of the corresponding class label for the specific fabric type in the FL database. The two selected models, CART and w/knn, were applied as regressors for three important specific fabric parameters from the FL database: (a) 'weight', (b) 'avg. bending rigidity' and (c) 'avg. shear rigidity'.

For CART, the complete set of 129 features was used for training purposes, in order to analyse in parallel the informative content or 'importance' of each shape feature. The dataset of 195 drape images (see Sect. 4.4.2.2) was tested with k-fold cross-validation techniques (Theodoridis and Koutroumbas 2006) in order to ensure robust and statistically significant results. Experiments with CART regression models were repeated with various configurations and selection of model parameters. The estimation of the prediction accuracy was based on the evaluation of the mean absolute prediction error (MAPE) in the normalised output range (target values):

$$\mathrm{MAPE}_{\mathrm{norm}} = \frac{1}{N}\sum_{k=1}^{N}\left(\frac{\left|y_k - \hat{y}_k\right|}{y_{\max} - y_{\min}}\right) \tag{4.2}$$

where N is the number of samples (predictions), y_k is the target value and $y_{\max}$–$y_{\min}$ is the output range.

The value of MAPE can also be considered as a rough estimate of the relative error (%) of the predicted values:

Similarly to the CART, the w/knn model was used in the form of a regressor, i.e., employing local averaging on the k closest 'neighbours' of the current input sample, with an option of a weighting profile against the distances (i.e. weighted average). Due to the nature and complexity of w/knn, a feature pre-selection step was employed in order to limit the dimension of the input vector to the top-10 (best) features, using a typical T-test univariate procedure for feature ranking (Theodoridis and Koutroumbas 2006). As in the case of CART, the dataset of 195 drape images (see Sect. 4.4.2.2) was tested with k-fold cross-validation techniques (Theodoridis and Koutroumbas 2006) in order to ensure robust and statistically significant results. Experiments with w/knn regression models were repeated with various configurations and selection of model parameters, and the regression error was considered in terms of mean absolute prediction error (MAPE) in the normalised output range, similarly to the CART case.

4.4.3 Results

The two selected models, CART and w/knn, were applied as regressors for three important specific fabric parameters from the FL database: (a) 'weight', (b) 'avg. bending rigidity' and (c) 'avg. shear rigidity'.

Table 4.8 Final results of the CART regression experiments

CART regressor: MAPE results						
	Weight		Avg. Bending Rigidity		Avg. Shear Rigidity	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
k-folds = 195	0.192	0.176	0.103	0.194	0.082	0.123
k-folds = 65	0.192	0.101	0.103	0.106	0.087	0.079
k-folds = 39	0.196	0.077	0.107	0.085	0.082	0.061
Average	**0.193**	**0.118**	**0.104**	**0.128**	**0.084**	**0.088**

Table 4.8 presents the final results of the CART regression experiments. The k-fold cross-validation was applied for $k = 195$ (leave-one-out mode), $k = 65$ and $k = 39$. The average and stdev values of MAPE have been calculated for each k-fold mode and for all k-fold modes.

Table 4.9 presents the final results of the w/knn regression experiments. The k-fold cross-validation was applied for $k = 195$ (leave-one-out mode), $k = 65$ and $k = 39$. The average and stdev values of MAPE have been calculated for each k-fold mode and for all k-fold modes. Average figures (in bold) indicate performance better than the corresponding CART regressors.

The results from Tables 4.8 and 4.9 show that the w/knn regressor performed better than the corresponding CART in all three cases, while the MAPE remained significantly small for the avg. bending and shear rigidity parameters.

As already pointed out, the number of available examples (drape images of known fabric samples) was quite low at the time of performing our evaluation tests. It is obvious that for any prediction method based on statistical inference or regression to yield reliable estimates of parameters of unknown fabrics, the number of 'example' samples is critical. The same applies to the appropriate selection of the examples so that they cover a wide spectrum of fabric categories in terms of their draping behaviour. This fact is illustrated in Fig. 4.20, where the dots represent known fabrics in the feature space. Only the three most significant drape

Table 4.9 Final results of the w/knn regression experiments. Average figures (in bold) indicate performance better than the corresponding CART regressors (overall best)

w/knn regressor: MAPE results						
	Weight		Avg. Bending Rigidity		Avg. Shear Rigidity	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
k-folds=195	0.162	0.139	0.065	0.110	0.075	0.108
k-folds=65	0.168	0.087	0.065	0.066	0.075	0.059
k-folds=39	0.168	0.067	0.065	0.050	0.076	0.047
Average	**0.166**	**0.098**	**0.065**	**0.075**	**0.075**	**0.072**

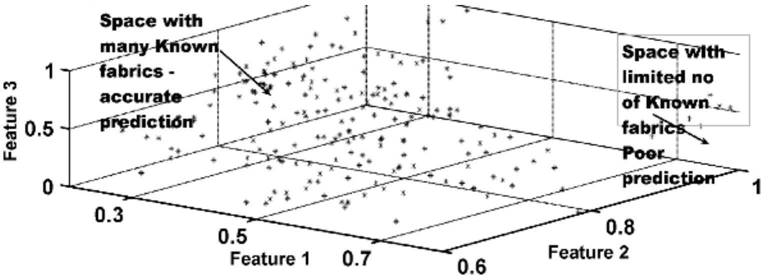


Fig. 4.20 Three-dimensional representation of the feature space (the three most significant features were selected) illustrating the need for selection of a large number of fabric samples with known parameters covering homogeneously all areas of the feature space

image features have been selected to represent the samples in a 3-dimensional coordinates feature space for reasons of better apprehension by a human observer. As expected, it was found that the prediction accuracy was higher when the position of the unknown fabric in the feature space was close to areas with many example neighbours (densely populated feature space). Therefore, it is expected that once the fabrics library is populated with, e.g. thousands of example fabrics, the proposed method will yield much more accurate and stable predictions.

4.4.4 Conclusions

A new method for the fast, economic and efficient estimation of some fabric parameters used for the simulation of fabric drape is reported. These parameters are currently identified by lengthy and expensive techniques (Kawabata, FAST, etc.). The task aimed at the automatic comparison of the shape of fabric drape of a sample of an unknown fabric with that of the drape of known fabrics in a fabrics library, based on image analysis of their corresponding projections when lying on a standard circular base (extension of the Cusic drape meter). Statistical methods (based on regression models) have been employed to enable the system to model the drape shape with size, orientation and even shape instance invariant features. This enabled the prediction of mechanical parameters such as average (warp and weft) shear rigidity and average bending rigidity with MAPEs (mean absolute percentage errors) over the whole normalised range of values, ranging around 7–10%. Considering the complexity of the problem, mainly due to the variable shape of the draped shadow image (different each time we repeat the experiment), the measured prediction range is a considerable achievement that may pave the way to other significant applications. Future research should focus on the task of devising an equally simple method for the estimation of elastic properties of the fabric, based on the same principle (automatic image analysis). Elasticity parameters are important not so much for the drape but for the fit and comfort estimation for tightly fit garments.

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Chapter 5
New Quality of Partnership in the Textile World – Concepts and Technologies

5.1 Introduction

Alexander Artschwager, Thomas Fischer, Dieter Stellmach

Abstract One core characteristic of the textile and clothing industry (TCI) is networking. The extended smart garment organisation (xSGO) framework will improve the interorganisational knowledge networking in a holistic way. Applying this xSGO framework, a new quality (of) partnership in the textile and clothing value-creation chain will be enabled. The xSGO framework comprises a configuration toolset, which allows modelling of and analyse an existing network for innovation and production, and to select and configure appropriate measures in order to improve the integration of activities and actors. Integrative components enable knowledge communication based on Moda-ML, and involve adapted RFID technologies, combined with a system for product tracing and tracking. In particular fast ramp up of new garment products in supply networks is conceptually and methodically improved. This section gives an overview about the holistic, system-oriented xSGO framework, explains details of quality harmonisation as one major component, and presents results of practical applications in the textile and clothing industry.

Enterprises of the textile and clothing industry (TCI) today are typically collaborating in worldwide networks with a high degree of dynamics. At the same time, development and manufacturing costs and time for providing textiles and garments of high quality, combined with decreasing innovation cycle times, and the emerging demand for personalised and individualised garments require a structured and transparent way of collaboration in networks.

Significant progress has been made in manufacturing technologies for textiles and garments, in garment-production automation of cutting, sewing and finishing. This progress – in particular in robotised handling of soft material or for joining of fabric pieces – is documented in some detail in Sect. 2.1 and Sect. 2.3 of this anthology.

New systems for product design and development enable collaborative virtual prototyping (CVP, for details see Sect. 4.3) by virtualisation of new garments. Textiles and garments with new and/or improved functionalities are also available or under development. In LEAPFROG for instance new shape-memory fibre-based textiles (for details see Sect. 3.1) have been developed.

Also new components and services for logistics and material flow are available today. World-wide acting logistic service providers enable a reliable and prompt delivery of garments, textiles and trimming materials. Significant progress has also been made during the last decade in information and communication technologies (ICT) for advanced product design, development, production planning and production control and for communication. Furthermore process control and even production itself (e.g. digital printing) is more and more digitised.

Each of these innovative technologies contributes to the improvement of the garment business, in particular to shorten lead times, to reduce costs of design, development and production, and to reduce stocks. But there is a significant need for a seamless integration of all of these components into existing or newly configured textile value-adding networks. The development of an appropriate framework for integration was significant part of the LEAPFROG project.

5.1.1 Integration for Networked TCI Organisations

5.1.1.1 Current Situation

As stated before the TCI is traditionally networking across a widespread textile community. Due to the complex production process of fibres, yarns, fabrics and garments the value-creation chain for the new product development and/or production of garments is sometimes composed of up to twenty partners.

In particular, garment development and manufacturing is carried out in worldwide networks. A typical situation is the following: Garment design and development are made in Europe, supported by a worldwide spread of design offices. Fabrics and other raw materials are sourced in the Far East and stored in the central storehouse at headquarters' site. Assembling is performed in Eastern Europe, and distribution to shops and wholesalers is conducted also centrally or at distribution centres. Fabric and garment conditioning (like testing, washing or repair) is executed by quality checking organisations in Europe or in the Far East. For innovative garments often weaving/knitting and finishing mills have to be involved directly in the new product development process. Finally transport and shipment is carried out by worldwide logistic organisations.

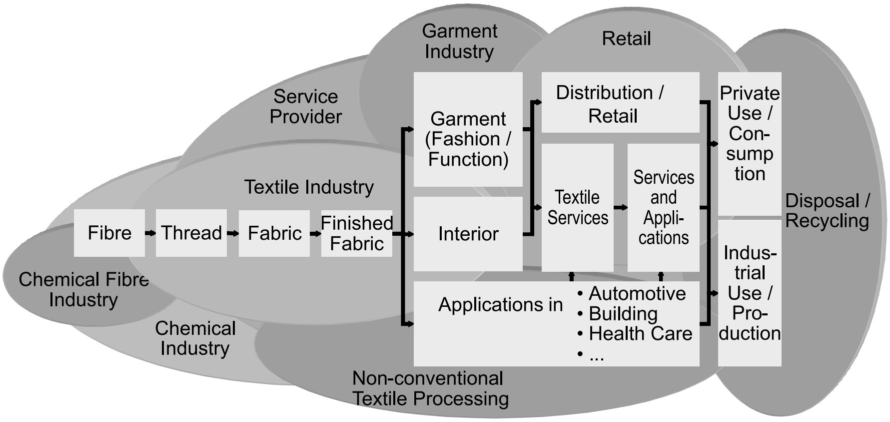

Fig. 5.1 The complexity of the textile world (Fischer and Rehm 2005)

It is obvious that business in such extensive networks is not easy to plan and to control. Networking requires cooperation and interfacing, physically and electronically as well. Physical interfaces, e.g. the dimension or the sizes of the transport pallet or containers for garments and textiles, are required to be identical at the sending and the receiving partners. The material data have to be harmonised: Weight, length or density of fabrics (and all other quality parameters) should be measured and declared in a standardised way.

Also, electronic interfaces have to fit, in particular in e-business/electronic communication. In particular, the meaning of information to be exchanged has to be identical. For instance, can the term ‘delivery date’ of a purchased good refer to the arrival at the warehouse, the electronic registration, or the release for further processing. Last but not least also organisational and cultural interfaces are of interest, in terms of language, time zone, or cooperation behaviour.

For some of these interoperability issues standards are available and widely used, such as, e.g. container dimensions, and no specific interfaces are required. But for many of these interoperations, e.g. those related to quality features or to order processing, efficient and effective interfaces are still needed for the harmonisation of quality procedures or the setup of electronic communication.

A comprehensive and systematic analysis of existing and potential fields of cooperation for global development and supply of textiles and garments can be based on the structure of Fig. 5.2.

Four typical business cases in the textile and garment sector have been identified:

- Case 1: Prototype development and prototype production inside of the company; duplication and production in distributed own factories;
- Case 2: Prototype development and prototype production inside the company; external duplication and production by third parties (cut-make-trim – CMT);
- Case 3: Collaborative prototype development and prototype production together with partners; duplication and production by third parties;
- Case 4: Full merchandise business.

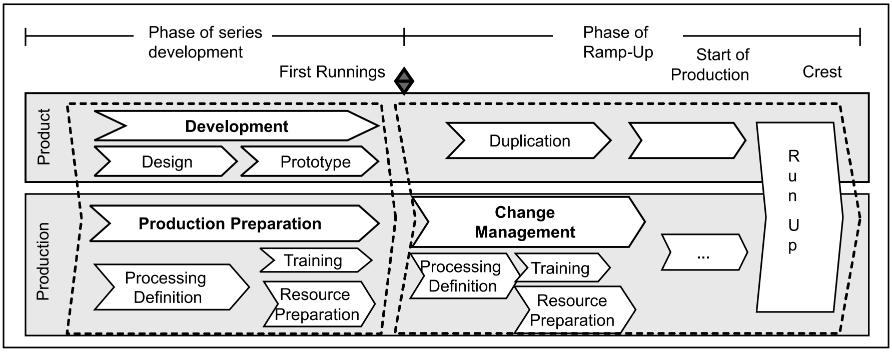

Fig. 5.2 Basic model for cooperation analysis and synthesis in the garment industry

For each business case an individual configuration of the network structure and appropriate tools are required. This is in particular necessary if new technologies are to be integrated.

Altogether networking is not a self-fulfilling or self-organising process. A lot of pre-conditions have to be met in order to setup networks and specific tools are necessary in order to operate a particular organisation in a particular network. The situation becomes even more difficult as new technologies for design, development and production become available, as developed in the LEAPFROG project. Accordingly for networking organisations along the textile value chain the aspect of integration is of significant importance.

Inadequate integration (of technologies) reduces performance not only if new technologies are wrongly introduced, but also in existing supply chains where technologies for design, production and logistics are not carefully harmonised. Today the mismatch between the potential performance of a certain technology and its real application is often enormous. Reasons for this are, for instance, unfulfilled pre-conditions, a lack of information and insufficient training of personnel or suboptimal configurations, in particular with respect to fast changing product requirements in the textile and garment world.

5.1.1.2 Conceptual Framework for 'New Quality (of) Partnership'

In order to improve the current situation in the TCI and to facilitate the set-up of partnerships and the operation of enterprises of the textile and clothing industry in networks, we developed in LEAPFROG the holistic framework of the 'extended smart garment organisation' (xSGO) (see Fig. 5.3), together with related components and guidelines for its implementation. This framework enables a consistent and coherent integration of already existing and/or new technologies into textile networks. The application of this framework in TCI networks will lead to a sustainable new quality (of) partnership.

The xSGO follows the conception of the smart organisation (Filos 2006, 2001). According to Filos a smart organisation requires networking in three dimensions:

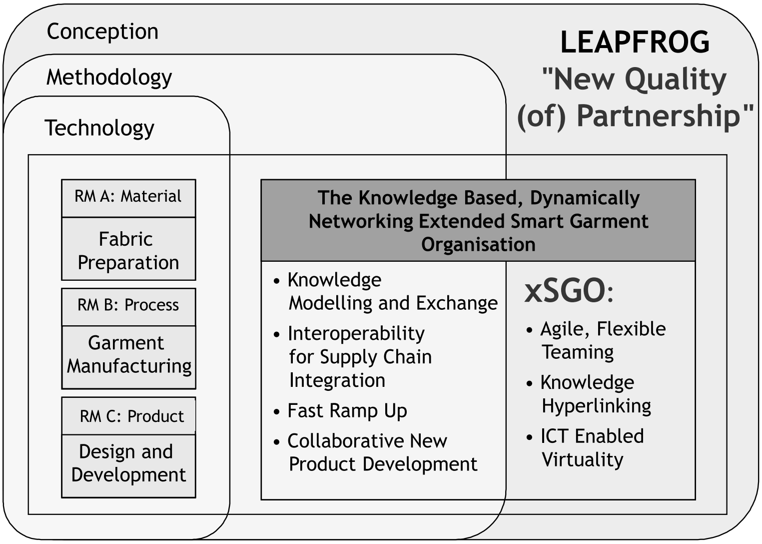

Fig. 5.3 LEAPFROG integration by the extended smart garment organisation conception

organisational networking, knowledge networking, and ICT networking. Further details are presented in Sect. 5.2 and Sect. 5.3.

This initial conception has been adopted, attuned to characteristics of the TCI and extended by appropriate methods and tools for networking and integration of product development and production. Particular focus is put on definition of and communication for interorganisational business processes as well as to product and process quality.

Knowledge networking features are at the core of the approach. Shared knowledge is being considered as an important resource, in particular in networks, where it is necessary to provide all required knowledge for an initiated process at the right place and time. Therefore, the xSGO methods and tools contain major knowledge networking functionalities.

All together a new quality (of) partnership in TCI will be enabled in terms of:

- new quality of organisations collaborating in networks;
- new quality of interoperation based on knowledge networking; and
- new quality of communication using ICT networking.

5.1.2 The xSGO Integration Toolset

The framework is functionalised by the components of the xSGO integration toolset that practically prepares and supports the integration of new technologies within TCI networks. These methods and technologies (see the components (1) to (8) in Table 5.1) have been developed by the LEAPFROG partners.

Table 5.1 Components of the xSGO integration toolset

			Supporting …			
Component	Name	Type	Organisational networking	Knowledge networking	ICT networking	Application in TCI
(1)	Quality Harmonisation	Method	X	X	x	Product design and development, production
(2)	Quality Wiki	Technology		X		Product design and development, production
(3)	Knowledge Exchange Infrastructure	Technology		X	x	Electronic communication
(4)	Product Tracking and Tracing	Technology			X	Supply Chain Management
(5)	RFID	Method			X	Supply Chain Management, MES[1]
(6)	AutoCost using Web Services	Technology			X	Development, production
(7)	xSGO Modelling Set	Method		x		Analysis and synthesis of networks
(8)	xSGO Configurator	Technology		x		Synthesis of networks

Quality harmonisation (see component (1) in Table 5.1) is one key issue of efficient collaboration in textile networks. Therefore appropriate tests have been implemented, which assist supplier relationship management. Details are described in the next section.

Knowledge orientation is supported by the quality Wiki (2) containing information about quality and colour management. It consists of Wiki pages containing know-how about textile materials, textile processes and testing procedures, as well as the description of competences the staff members need, and learning material to achieve these competences, and also significant information about colour aspects in textiles and garments. It is used for documentation, and for information and training of involved personnel.

The actual definition and setup of e-business collaboration is facilitated by the knowledge-exchange infrastructure (3) that uses a common ontology. It enables sharing of knowledge on materials, products and processes between partners along the textile chain. For details see Sect. 5.4.

Organisational networking and knowledge networking are closely related to ICT networking. Therefore, the toolset contains a number of technological specifications and software systems, like the product tracking and tracing system ((4), for details see Sect. 5.5). This system enables a complete and seamless single-part follow-up along the value chain, from supplier of fabrics (and all other materials) to production

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[1] Manufacturing execution system: Production management system operating near to processes

partners up to the end consumer. One industrial application of this functionality is offered by the LEAPFROG partner Bivolino (http://www.bivolino.com), who is a provider of mass-customised garments for the consumer over the Internet.

RFID (5) is used for identification of textiles and garments, which are transported within and between factories, warehouses, and shops. Major information about the individual fabric is available directly, and can be read contactless and regardless of orientation/direction of the fabric. UHF RFID tags have been adapted to be robust enough not to be destroyed during process treatment for fabrics and garments finishing (e.g. dyeing, washing, or tumbling). One type of tag is integrated into the garment label and is based on a textile substrate, while the second type of tags is fixed on a plastic substrate. Both commercially available tag types are suited for textile and garment production and logistics. Additional data can be stored on the tag, for the purpose of quality management or as an anti-counterfeiting task.

Moreover, ICT networking today is based on web services. This technology for flexible interoperation of software has been implemented into appropriate product data management systems (PDM) for garments. Based on this technology LEAPFROG partner Assyst has developed and implemented the web-based tool AutoCost (6, see http://www.autocost.de). This tool makes it possible to minimise the cost of a production order at hand by an optimal combination of markers with different size combinations and the corresponding spreading of fabrics. The collaborative virtual prototyping (CVP) platform and its components developed in another research module of LEAPFROG are also using web services (for details see Sect. 4.3).

The xSGO framework comprises two tools for the establishment of new quality partnerships in textile supply chains. The xSGO modelling set (7) allows modelling and analysis of networks for innovation and production, with particular focus to the coherent description of the knowledge networking issues. Details are described in Sect. 5.3. The xSGO Configurator (8) is a web-based decision support system, enabling visualisation and navigation for identifying, selecting and designing innovative methods and technologies for the TCI, in order to improve the integration of activities and actors.

5.1.3 Improved Collaboration for Quality Assurance

An important aspect of interoperation of enterprises applying the xSGO framework is the assurance of quality. The fulfilment of certain fabric characteristics has a big impact not only on the quality of the garments itself, but also on the manufacturing processes of the garment industry.

A typical process of fabric sourcing is as follows: A garment company orders fabrics from a supplier of appropriate textiles, e.g. from a weaving company or a knitwear producer. Regularly the raw fabric is sent to a finishing company for further treatment, which often is pre-defined by designers of the fabric producers.

After the finished fabric has been checked for certain physical and optical requirements, it is sent to the (central) raw material warehouse of the garment company. There, further tests are executed. Finally, this fabric is delivered to a garment manufacturing site, where it will be cut into fabric pieces, which are joined to the final garment.

Today, finished fabrics are checked several times for the same requirements by various partners along the supply chain. Because of this procedure of multiple testing, it is currently necessary to ship the finished fabric to the fabric storehouse of the clothing company. If the quality is adequate, the fabrics will be passed to the garment assembling sites that may be located anywhere in the world.

This costly and time-consuming procedure is going to be changed. Quality harmonisation (which is component (1) of the xSGO integration toolset) enables removal of multiple tests, as well as the unnecessary shipment to central fabric warehouses. Such processes that do not add value can be eliminated.

An approach that will strengthen the cooperation between the textile and garment industry will lead to an industrial partnership, in which the partners will perform direct delivery from supplier sites to customers manufacturing sites. Fast provision of perfect material to the production site, in both the product development phase and the regular manufacturing phase of garments will significantly improve the business relationship. Key components of the approach are:

- An audit component that enables the collaborative analysis of the specific role of the textile partners for the requested quality of the garment, the identification of gaps, and the definition of steps for improving supplier quality. This component relates to organisational networking.
- A quality component that comprises a global quality and product guideline based on quality standards, specific testing methods and clearly defined processes within the quality-management network (knowledge networking). The starting point is a round-robin test, which enables the matching of the inspection systems.
- A communication structure for the identification and specification of quality related communication processes and rules during the development and production phase (ICT networking).

Audit Component

The collaboration between supplier (weaving company) and producer (clothing company) establishes a certain degree of organisational networking, based on a status classification of each supplier. This classification results from an appropriate auditing, where the status can vary from zero (0) to three (3). A status (0)-supplier is using an adjusted visual fabric inspection system, has signed specific delivery agreements, and has offered sufficient information about his quality management. An audited supplier can reach status (1), when his quote of reclamation is less than a certain limit. A status (2)-supplier has attended a round-robin test and is using an audited testing system with adjusted testing methods, tools and documentation. The process capability is guaranteed due to a process failure mode and effects analysis (process-FMEA), which deals with the production processes and their possible failures during weaving, preparation of weaving and post-processing.

The highest level a supplier can reach is status (3) allowing the direct delivery of fabrics via distribution centres or to production sites in the supply chain. This includes also tracking and tracing of goods at production, logistics and warehouse sites, a well-organised management of deviations and regulations for order management.

Quality Component

One key issue is to ensure the matching of the inspection systems used by the participating partners. They need identical reliable information about the specifications and the quality of the finished fabric. This means that they have to use the identical test equipments, the same standard of testing procedures, and comparable measurement methods.

Therefore, a round-robin test has to be performed: The network partners will make several tests with different types of finished fabrics. The tests comprise mechanical inspections (e.g. pilling tendency, or abrasion resistance), chemical inspections (e.g. cleaning fastness, light fastness or acid fastness), geometric inspections (e.g. mass per unit or edge symmetry) and fabric inspections (e.g. defects). Before starting the test the participating partners have to identify the testing methods to be applied, the minimum requirements, and the material information.

After these inspections, the results will be compared. If the discrepancies are in a tolerable range, the round-robin test is regarded to be successful, and the major requirement for quality harmonisation is fulfilled.

Communication Structure

Supplier relationship management and quality partnership in general requires appropriate adaptation of internal data model of the ICT systems involved in the data-exchange process. Quality data must be recorded, processed and communicated to partners along the textile supply chain. This can be done by the following means of ICT and knowledge-management technologies:

- The knowledge-exchange architecture for a standardised e-business collaboration along the supply chain in the TCI.
- The product tracking system enables to communicate data, and to plan and control the fulfilment process and the related flow of material and products in the supply chain.
- RFID technology enables to identify the fabrics in production and logistics, and to store the individual (quality) data directly on the fabric.

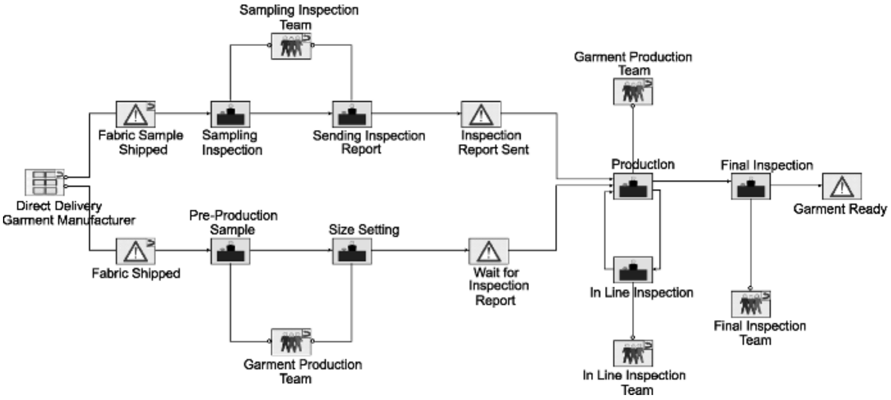

Fig. 5.4 The xSGO activity diagram of the organisational layer for Direct Delivery in a garment organisation

All components together enable direct delivery of fabrics from the weaving company to the garment production site, avoiding double tests and saving time and cost. As a first step of implementation of a quality harmonisation in a textile supply chain, the current state of the material flow, the value-creating processes, and the quality inspection processes of involved partners have to be analysed and visualised using xSGO models in order to describe the as-is situation.

The next step is the round-robin test, followed by the implementation of the supplier qualification. The FMEA has to be performed by textile suppliers, the required communication structure can be implemented in parallel. Finally, the direct delivery can be agreed between the partners and subsequently applied. These new procedures will be described and documented with the xSGO modelling set (see Fig. 5.4).

5.1.4 Practical Experiences

The new quality (of) partnership was implemented in 2007 in an industrial environment at the Hugo Boss headquarter in Metzingen, Germany, together with the fabric supplier Zuleeg in Helmbrechts, Germany, the supplier of finishing services Knopfs Sohn, and the quality test organisation Profitex, both Germany (see Fig. 5.5). The Centre of Management Research at the German Institutes for Textile and Fibre Research Denkendorf (DITF-MR) provided the conceptual and scientific expertise and managed this pilot implementation.

The objective was to enable direct supply of fabrics to the production sites of Hugo Boss using in particular quality harmonisation (component (1)).

At the beginning of the project a cooperation agreement was signed. This included, e.g. the specification of the garment types (in this case men’s suits) and of the fabrics and the finishing type (coloured woven woollen fabrics), the selection of the involved testing locations (Helmbrechts, Germany; Metzingen, Germany), and the classical project issues (timing, responsibility, resources, …)

- Quality component: A comprehensive round-robin test has been executed. First the team selected the fabric parameters that had to be checked. Then they documented the testing methods and instruments. The fabrics were selected, and measured at the different testing locations. The testing values were documented and compared. After some corrections and modifications, the testing methods were harmonised.
  Zuleeg performed the failure mode and effects analysis (FMEA) for the weaving process. During workshops for 5 process steps critical failures and more than 50 measures for prevention were identified. Half of them were implemented immediately, leading to a reduction of quality costs for weaving of approx. 75%.
- Audit component: The structure of the supplier classification has been implemented in the structure of the Hugo Boss supplier relationship management system, which is part of their SAP application system. More than 300 suppliers were assessed, and Zuleeg became one out of 10 suppliers with reliable processes (status (2)), who received status (3) ‘enabled for direct delivery’.

Since 2007 Zuleeg is certified to deliver its fabrics directly to the production sites of Hugo Boss. Thus, a significant amount of time and cost can be saved. Hugo Boss has communicated this concept to its suppliers, and in 2008 further German weaving companies started with the implementation of the new quality (of) partnership. Information and training of the involved actors is done with the quality Wiki.

Also in 2008 the transfer to Ermenegildo Zegna, a world leader in luxury men's clothing headquartered in Italy, has been started. The structure and methods were adapted for the processes of production and supply at Ermenegildo Zegna with the support of DITF-MR. Further available practical experiences of establishing components of the xSGO framework in industrial environments are reported in the following sections.

Fig. 5.5 The pilot value-creation chain applying new quality (of) partnership

5.1.5 Outlook

The framework of the extended smart garment organisation (xSGO) for networking of TCI enterprises enables a new quality (of) partnership. Flexibility and adaptivity to fast-changing market requirements and new technologies will be enhanced, quality problems, throughput times, stock levels and related costs reduced. A coherent integration of new technologies, in particular of the LEAPFROG results, into networking industrial organisations will be simplified.

Major focus is the quality assurance along the textile value-creation chain. In order to reduce quality problems, to remove double tests, and to enable a direct supply of fabrics to the garments production site, the round-robin test for testing harmonisation, the FMEA for process capability and the supplier classification have to be applied. The xSGO modelling set is best suited for analysis and during the design and set-up phase of the new quality (of) partnership. A quality Wiki is used to inform and to train the personnel involved in the implementation and in daily application. This quality Wiki also includes information about a new colour-management structure, which consists of a virtual colour model based on real colour books using the L*a*b colour spaces.

The xSGO framework and the methods were developed with and are successfully implemented at industrial LEAPFROG partners. They expect the following benefits:

- a reduction of production errors and quality faults from currently 15–20% to nearly zero;
- a decrease of processing time in geographically dispersed production networks due to the removal of testing processes, direct delivery and reduced rework;
- a reduction of average lead times of up to 25%; and
- a decrease of fabric stocks at textile and garment manufacturers' warehouses.

The holistic, system-oriented concept allows flexible networking, in terms of organisational networking, knowledge networking, and ICT networking. The demonstrated economic benefits of networking industrial communities show interesting potential for strengthening of the European textile and clothing industry.

5.2 Engineering Value Networks in the Fashion Industry

Ramón Yepes

Abstract The chapter starts with an overview of the extended smart garment organisation (xSGO) concept. Under the name xSGO we refer in LEAPFROG to innovative value networks that can achieve and sustain competitive advantage in today's turbulent fashion market. The xSGO is at the intersection of the advanced information and communication technologies (ICT), the new collaborative cross-organisational models and the knowledge driven orientation as the main source of

competitive advantage. First we analyse the role of value networks in fashion with an overview of the principles of organisational economics. Then the role of ICTs as enablers of the new business models is analysed and some real fashion value networks are quickly presented. Finally, a generic methodology is presented on how to take the architectural decisions to engineer fashion value networks.

5.2.1 *The Emerging Organisation Models*

The worldwide liberalisation of trade, finance and investment coupled with the worldwide spreading of technical knowledge and the advances in ICT, transport and other technologies, is accelerating the pace of change and opening vast opportunities and challenges for enterprises, in all economic sectors.

Dynamic enterprises have responded to these opportunities and challenges, by exploiting the expanded base of competitive partners and suppliers and establishing with them a more proactive and collaborative relationship than the traditional one-time supplier–purchaser relationship. One of the most significant developments in management and business thinking has been to recognise that networks of closely collaborating companies operating as an integrated value network or supply network, can exhibit in an excellent degree sustainable economic performance, consumer responsiveness, flexibility and adaptability to changes in market conditions. Furthermore, new interactions and collaborations are causing an accelerated growth of knowledge that is the basis for futures advances.

The xSGO ‘extended garment organisation’ concept was introduced in LEAPFROG (Fischer 2008) to provide organisational reference models useful for companies to think about how the industry, the companies and their value network will change in the future and in this way promote the competitiveness of the European fashion industry. We explored in LEAPFROG the features of these new models, the opportunities and challenges they represent for the fashion industry and the organisational and technical changes the companies should undertake to develop the competences required to benefit from them. The aim was to design fashion supply networks that manage knowledge to achieve competitive advantage.

Traditionally, the competitive advantage of a business is considered to come from its core internal competences and its internal business processes that are considered as somehow static and permanent, and the strategy of a company is aimed at improving their core competences and their business processes. However, in the new business models, the core competences of a business need to be continually adapted to the network conditions and acquire a dynamic nature.

The business has to be considered as an entity in continuous communication with its network partners. To gain and sustain competitive advantage the business must focus on leveraging the collective capabilities of the network as much as its internal capabilities. The potential gains of interenterprise collaboration are so significant that a business strategy focusing just on the direct customers and internal functions risks to be short-sighted.

One AMR-Research study (AMR Research 2004) quantifies the advantages associated to first class networking enterprises as: 15% less inventory; 17% stronger order fulfilment; 35% shorter cash-to-cash cycle time. These advantages translate into: a 60% increase in profit margins; 65% better EPS (earnings per share); and 2-3 times better ROA (return on assets).

5.2.2 The xSGO Paradigm

Smart organisations (SO), (Filos 2000, 2006) are new forms of industrial organisations that exploit the great number of exchanges and relationships, 'the wisdom of networks', for enhanced learning, improved competitive advantage. In the European Commission's research program Information Society Technologies IST-2002 (Filos 2006), a SO is defined as: a knowledge-driven, internetworked, dynamically adaptive to new organisational forms and practices, learning as well as agile in their ability to create and exploit the opportunities offered by the new economy. The main features of the SO are:

- The SO is based on networking at different levels: technological, organisational and learning through knowledge acquisition and sharing.
- The SO focus moves from ownership and control of tangible assets to the exploitation of knowledge as the key source for competitive advantage.
- The SO is capable of continuous knowledge interactions with external partners. These interactions, referred by (Filos 2000, 2006) as 'knowledge hyper-linking', are considered in LEAPFROG as human-centric, driven by people who share common interests and objectives and are not envisaged as limited to just ICT interactions.
- The SO departs from the strictly functional hierarchy, towards a more effective and efficient combination of functional hierarchy and cross-functional project-teams who act based on coordination and inspiration led by authority of competence, and guided by trust and integrity.
- The capacity to collaborate is a core competence of the SO, because of the acknowledgment that many of the skills and resources essential to the organisation's competences are external and outside of the direct control of the management. This fact demands for a wide variety of collaborative partnerships.
- The SO is fully committed to empowering and leveraging people through an entrepreneurial culture.

An extended smart organisation (xSO) is a smart organisation that develops its business in a network of more or less loosely tied companies that cooperate as if they were a single virtual company. The vision is that in the global environment competition is no longer a question of one company against another company but of one network against another network. When an xSO leads a network, usually, it does not own nor control the resources of the other partners nor can it impose coordination by command as in a vertically integrated company, but it has the ability to connect to the resources when needed and to design a space of collaboration and commitment among the partners in the network. Summarising, an xSO is an organisation having the following features (Fischer 2008):

- ability to design, implement and run business networks and/or ability to quickly establish cooperative relationship in a business network;
- a business culture focused on customers' needs and centred on collaboration and knowledge improvement;
- ability to respond flexibly to market changes and to adapt its internal and external behaviour to widely changing business conditions.

Extended smart garment organisations (xSGO) are xSOs operating in the fashion industry. Achieving smartness in the fashion industry requires leveraging the right ICT and fashion technologies, such as: web collaboration, 2D and 3D CAD, virtual prototyping, product lifecycle management (PLM), or workflow management. These technologies play a crucial role as enablers of the new organisation models envisaged in LEAPFROG.

The role of ICTs is an enabling one but its benefits can be realised only by redesigning the business processes and re-organising the knowledge flows that support them. This is why the xSGO modelling set (see Sect. 5.3) provides three integrated cross-organisation views: the process/organisation view, the knowledge view, and the technology view.

Business relevance usually requires an holistic approach both technical and organisational covering different business areas such as product development, manufacturing processes and supply chain architecture as exemplified in Benetton's success that came from simultaneous innovations in product (meeting customer's colour preferences, etc.), in process (POS data acquisition and dyeing full knitted sweaters) and in supply chain (achieving volume managing a network of subcontractors).

Business processes distributed through the network should behave like a unique process inside a single virtual organisation. This is a must for the creation of competitive advantage from the linkages with the other partners. The LEAPFROG's knowledge-exchange architecture (see Sect. 5.4) initiative is supporting this level of integration.

5.2.3 Value Networks

Porter (1985) defined value as: "What buyers are willing to pay for a product or service", this concept has been extended to include other aspects as: coworker value, social value, environmental value and shareholder value. Porter also introduced the value-chain concept as a tool for designing the strategy of the firm that is "a general framework for thinking strategically about activities involved in any business and assessing their relative cost and role in differentiation". The Porter value chain is extended to the value network concept consisting in the set of activities carried out by the different companies involved in the design, production and marketing of a product. Child (2001) defines a value network as a "value creating system of several organizations possessing complementary strengths and coordinated through a combination of contractual provisions and mutual beneficial relationship that are often orchestrated by a leading member".

Figure 5.6 shows one type of loose fashion network composed of a universe of potential suppliers. The orchestrator configures one specific 'supply chain', for each customer order by selecting the right companies and coordinates their activities to assure that the customer order is properly fulfilled.

The focus of the value network is not the manufactured product nor the manufacturing costs but the value created for the end customers. The only reason for the network to exist is to deliver value to customers in the form of the right product, at the right time, at the right place and at the right price.

A value network is supported by three pillars: The value-adding activities (process), the organisational structure and the enabling technologies, and requires the precise coordination of four different flow exchanges: Materials, information, financial and knowledge.

All these flows are described by the xSGO modeller. In particular, the knowledge flows have been accorded a significant role because scientific, technical and organisational knowledge is essential to achieve continuous economic growth. At the level of the firm, the organisational interaction between 'explicit knowledge' that is easily communicable and 'tacit knowledge', that comes from experience and cannot be communicated by workers under excessively formalised management procedures is at the source of innovation and (Nonaka 1995): "sources of innovation multiply when organizations are able to establish bridges to transfer tacit into explicit knowledge, explicit into tacit knowledge, tacit into tacit and explicit into explicit". ICTs are instrumental in building these bridges.

The key property of knowledge is that once it has been created it can be used by any number of firms at the same time and can accumulate without bound. This is described as knowledge being a non-rival good not subject to the diminishing returns law as physical goods are. Knowledge is, however, a partially excludable

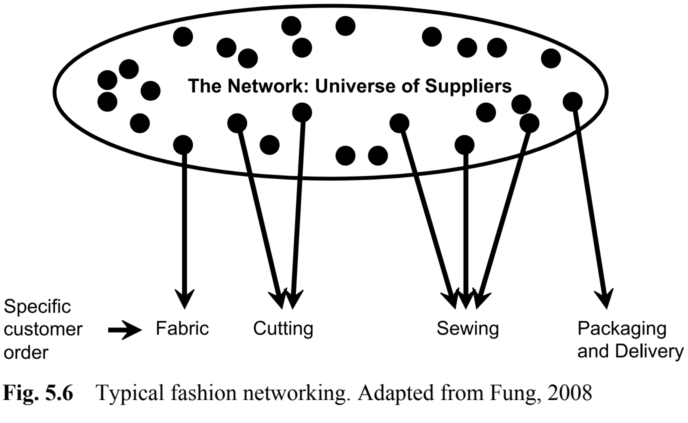

Fig. 5.6 Typical fashion networking. Adapted from Fung, 2008

good, meaning that people who create new knowledge have the capability to exclude others from using it to their benefit, and so knowledge gives the owner some market power to recover the investment made. Excludability is only partial because knowledge necessarily spills over in time through diffusion.

Because knowledge is not subject to diminishing returns, firms exploiting knowledge can be price makers not price takers, and the markets for their differentiated products are, as a rule, competitive monopolistic markets.

5.2.3.1 Market vs. Hierarchies

The organisational economics (OE) provides the theoretical framework to decide which activities are better conducted within firms and which between firms, that is: when to make, when to buy and when to cooperate. OE is considered to have started with Coase's paper: *The nature of the firm*, where he asked why certain activities are done inside the firms while others are contracted in the market and even why firms existed at all (Coase 1937, 1991), "I found the answer by the summer of 1932. It was to realize that there were costs of using the pricing mechanism. What the prices are has to be discovered. There are negotiations to be undertaken, contracts have to be drawn up, inspections have to be made, arrangements have to be made to settle disputes, and so on. These costs have come to be known as transaction costs."

Williamson (1985) considers the transaction costs (TC) as those costs incurred by agents due to the non-ideal nature of the economic system. In an ideal perfect market with complete information shared by all agents and perfect competition among all factors, there would be no TCs; TCs are the costs due to the departure of the real market from the ideal. Using the market has costs, and using the hierarchy of management inside the firm has also its own coordination costs as happens to all the hybrid schemes like: joint ventures; network partnering; strategic alliances, etc.

Basically, what OE has to say on whether to make, buy, or cooperate is that a given transaction will be done in the kind of organisation with lower transaction cost.

OE considering the risks in cooperation created by the bounded rationality and opportunism (two features of human nature, as Williamson points out) predicts that the transaction costs will be lower in a hierarchy (a firm) the higher the uncertainty and the higher the asset specificity of the transaction. Therefore, OE indicates that highly uncertain and highly assets specific transactions would usually be carried out more efficiently inside the firm than in the market.

5.2.3.2 The Role of ICT in Value Networks

ICTs are considered as tools to enable coordination and lower its costs. ICTs have the capability to dissolve some tradeoffs of the clothing business such as the trade-off between increasing differentiation and shorter time to market; the trade-off between low inventory levels and high customer service level and the trade-off between higher flexibility and lower manufacturing costs.

There are two basic ways to deploy ICT in a business network: To be deployed by a lead company who forces the partners to adopt the technology or to be deployed by interconnecting the IT systems of the partners. The first approach is used in some of the largest cooperation platforms such as the retail link from Wal-Mart. The LEAPFROG KEI has been developed to facilitate the second approach of interconnecting the IT systems of the partners through extensive use of international standards such as ebXML.

In any case, there is a most critical error to be avoided, (Bar, 1993): "IT often automates inefficient ways of doing things. Realizing the potential of IT requires substantial reorganization." ICT networking is only an enabling technology, but it is not sufficient to exploit the full potential of networks.

5.2.3.3 Performance Metrics for Value Networks

The classical performance metrics for supply networks have been: Cost, quality and speed. Lee (2004) introduced the so called triple A metric, best suitable for the textile and clothing industry:

- agility to match supply with a highly variable demand is measured by time-to-market, time-to-serve and time-to-react.
- adaptability of the network structure to longer term structural market changes or to shifts in strategies, regulations, products or technologies;
- alignment of the economic interest of the partners determined by the right economic incentives put in place in the network to induce the partners to collaborate.

5.2.3.4 Typology of Value Networks

As a guide in the analysis and engineering of business networks, it is useful to classify the business networks according to the following criteria:

- Planned duration of the network: Temporal, permanent, or hybrid.
- Geographical extension: Worldwide, regional or local as in clusters of economic districts.
- Origin: Family-based networks, as in China or Italy; Hierarchical communal networks as the Japanese Keiretsu; decentralised corporate units from former vertically integrated companies; cross-border networks from strategic alliances.
- Sectors of activity: Horizontal networks operate in all main economic sectors, and have own sources of financing. The Korean Chaebol is controlled by a central holding, owned by a family and backed by a government bank (e.g. Hyundai, Samsung, etc.). The Japanese Keiretsu is a Vertical Networks with hundreds of partners built around large corporations (such as Toyota, or Nissan).

- Structure: Static (no change of partners) or dynamic (membership can change).
- Operational principle: Supply-driven networks and demand-driven networks typical for the textile and clothing industry.
- Participation: exclusive where participation is allowed in only one network versus non-exclusive.
- Governance (terms according to which, control, responsibilities, benefits and risks are shared among the members of a network): Free market where the relationship is limited to market transactions that do not require further collaboration. Pure integration when one of the companies is vertically integrated inside the other. Orchestration when one of the players coordinates all the others in the network and keep them aligned through a set of incentives. Coercion when a lead company exercises its buying or other power to force all players to take coordinated actions.
- Information visibility level: High or low. Visibility is necessary to avoid inefficiencies such as duplicated inventories, and the consequences of the bullwhip effect (Lee 1997).

5.2.4 Fashion Networks

5.2.4.1 Fashion Products

The goods sold in the fashion market are garments or accessories that can be classified in different categories, (Abernathy 1999) as:

- *Basic products* are commodities as knit underwear, hosiery and home textiles that change little from year to year and are purchased mainly on price, with relatively stable demand along the year, and sold at low margins. The supply network is oriented to mass production trying to minimise total costs.
- *Fashion basic products* with low-quality fabrics and some element of style like dress shirts, or knit sportswear are offered in many different styles with small variations. They are sold at relatively low prices, their supply is not much connected to fashion trends, and are well adapted to be mass produced in not very fast overseas supply chains.
- *Fast fashion products* are more fashion conscious and were introduced to get improved margins, better brand image and higher turnout at retail. They follow fashion trends and quickly make new designs to be delivered in few weeks to the stores, at affordable prices with intended shelf life of just 2 to 3 weeks.
- *High-fashion products* have a lot of style and design and use quality fabrics. Examples are high-quality ready-to-wear women's dresses, fashion skirts, designer collections and 'haute couture'.

The demand of products with significant fashion content depends on volatile consumer tastes and fashion trends that could last for just a short time window and are often connected to ephemeral events like a catwalk, a celebrity style, or a music event. In particular, fast fashion demand cannot be forecasted. The uncertainty on styles, colours and quantities is greater the farther ahead from the season these decisions are taken. Forecast errors can be up to ±40% if done 5 months ahead and worsen with product variety because there is less demand history to use in forecasting. This stresses the importance of capturing true customer demand.

As stated before, the design, production and provision of textile and fashion goods is performed by a network of companies. The activities in these fashion value networks can be grouped in the following segments: Raw material suppliers: natural and synthetic fibres; textile companies that supply yarn and fabric; garment manufacturers including domestic and overseas contractors; export channels and retailers, as indicated in Fig. 5.1.

5.2.4.2 Real Fashion Networks

The Traditional Fashion Supply Chain and the Quick Response (QR) Movement

The traditional fashion supply chain was push oriented (Hunter 1990) and had the following features: New collections were designed about one year ahead of the season; the stores placed orders to manufacturers from five to seven months ahead of the season, based on their forecast of styles, colours and quantities; the manufacturers produced most of the goods before the season and accumulated inventory during the season, replenishment was very limited and at the end of the season more than 30% unsold products had to be heavily marked down to be sold.

The quick response movement (QR) (Abernathy 1999) started in the U.S. in the 1980s and tried to move the retailer buying process closer to the selling season by the systematic introduction of ICTs, such as CAD, PDM, CAM, marker optimisation, and flexible manufacturing technologies enabling production in small batches in different stages of the apparel supply chain.

Stores would commit only to a percentage of the merchandise before the start of the season, deciding on the rest of the preferred styles and colours after observing the real customer demand.

The Fast Fashion Supply Chain

To analyse this segment we focus on Inditex, better known by its brand Zara, supply chain that is extensively documented. The main characteristics of the Inditex supply chain are as described in (Fraiman, 2005; Ferdows 2004; McAfee 2004; Caro 2007; Lessard 2008) and in the 2008 Inditex Annual Report are:

- The total revenue in 2007 was € 9435 billion. In September 2008 they opened their 4000th store worldwide. Inditex markdowns only 2.6%, while industry average is 10–20%. IT budget is 0.5% and advertising is just 0.3% of sales.
- Inditex is mostly a vertically integrated company that outsources only the sewing operations or the base products like sweaters in classic colours, mainly to

Europe. 60% of the fabrics are externally sourced, mostly as undyed. The supply chain is a mix of push and pull, Inditex delivers only 50% of the goods at the start of the season, while the rest are freshly designed in-season.

- Low-performing products are quickly slashed and new fresh designs are introduced (over 30,000/year) by its more than 350 designers. They create a scarcity premium, to stimulate impulse purchase and visits to the stores.
- Inditex's stores are uniform, upscale and located in premium shopping streets. Most of them (90%) are own managed, and 80% of its business is in Europe. Store managers are highly empowered and manage the store's inventory, ordering products weekly and providing daily customer feedback. All stores receive goods twice per week from the company distribution centres (DCs).

The Prato Textile District

One very efficient cluster in the textile sector is the Prato district in Tuscany Italy (Lazaretti et al. 2001, 2004; Incagli 2004). Prato is a town of about 300,000 inhabitants with a long textile tradition from the 12th century that was once based mainly on vertically integrated companies formed around large woollen mills. In the 1980s Prato suffered a deep structural crisis, which it overcame by shifting from a few low-price and low-margin products to a higher variety of innovative woven fashion fabrics and garments, supplied quickly and at competitive prices. There are in Prato over 7000 companies, employing over 50,000 people producing a total of 4.2 billion €. Knowledge of textiles and clothing is socially appreciated and there are good technical education sites. Small family businesses specialised on parts of the production process are collaborating and orchestrated by the 'impannatori'. The impannatori rely on the specialised small-scale weavers who supply them at competitive prices and experiment with materials and equipment. The relationship between the impannatori and his network is very fluid, based on complementary skills and trust, which enables the fast dynamic configuration of a network and its adaptation to changing customer demand and that can expand its capacity to respond to peaks by incorporating new subcontractors through their horizontal links without the need of complex negotiations. The impannatori often even provide informal credit to their subcontractors to be later deducted from the amount the impannatori pays to the subcontractor for the goods they manufacture. The trust relationship strongly reduces the risk.

The Li & Fung Orchestration Model

Li & Fung Ltd. (L&F) was founded in 1906 in Guangzhou, today it is based in Hong Kong and is the largest trading company in the world in outsourcing apparel. L&F made a total turnover of US$ 11 billion in 2007 (Li & Fung Annual Report 2007). L&F operates 80 offices covering 40 countries. L&F does not own a factory, but produces over 2 billion garments on behalf of over 1000 American and European retailers orchestrating a network of more than 8000 factories in Asia and other continents. L&F provides to retailers a total value-added package and relies heavily on ICT (L&F was listed in 2005 in the Wired 40, side by side with Google, Yahoo). The relationship of L&F with the contractors on long-term contracts akin to the so called '30/70' (Fung et al. 2008): "L&F to have more than 30 percent of the business of a given supplier, to be meaningful and ensure commitment, but no more than 70 percent of its capacity, to ensure flexibility and encourage learning."

5.2.5 The Design of Fashion Networks

The design of fashion value networks consists in taking the right set of decisions at strategic, tactical and operational levels to optimise the value delivered to customers. At a strategic level, the main issue is to decide on what capabilities to invest and develop internally and what capabilities to allocate for development by suppliers; combined with this decision is the formation of partnerships with the suppliers. The following methodology on the high-level design of fashion value networks is based on (Fine 2000; Diaz 2005; Christopher 2006). It consists of the following steps:

- identification of strategic parameters to be decided in the design process;
- statement of the competitive strategy approach of the firm;
- mapping the external competitive environment of the firm;
- mapping the internal capabilities and constraints;
- prescription of the architecture of the value network.

Step 1: Identification of Strategic Parameters to be Decided Upon

Some of the most important strategic parameters are:

- the flow model: forecast driven, demand driven or hybrid;
- the location of inventory: centralised or distributed;
- the make/buy decisions;
- the relationship with the partners should be: transactional or long term;
- the geographical distribution: local or global.

Step 2: Statement of the Competitive Strategy of the Firm

This is the first input to consider in deciding on the configuration parameters. Shapiro identifies three generic strategies for a firm:

- competition in cost;
- competition in customer service;
- competition in innovation.

Table 5.2 Priorities of strategic objectives of selected fashion groups (adapted from Diaz 2005)

	Zara	H&M	Gap
Optimise on (A)	Innovation	Cost	Cost
Bound on (B)	Cost	Innovation	Service
Best-effort on (C)	Service	Service	Innovation

This classification is considered exhaustive and supported by empirical evidence. Companies may aim at more than one strategic objective. The highest priority objective (A) should be the one to be optimised; the second (B) would behave like a constraint that must be met, and the third (C) is free. Typical examples are shown in Table 5.2.

The strategic objectives are translated into specific metrics: The objective cost is related to the metrics Efficiency. Customer service is related to reliability and responsiveness and innovation to flexibility, sensitiveness and adaptability.

For example, to focus on innovation it must be possible to frequently introduce new products and to either ramp up production or slash the product according to performance. Therefore, network flexibility is a must and the network must sense the real customer demand (sensitiveness) and be ready to support the introduction of new products (adaptability).

If cost were the strategic priority then the network should be geared toward Efficiency.

Step 3: Mapping the Competitive Environment

The competitive environment (Fine 2000) is shaped by constraints that may limit the feasible values for the configuration of the supply chain, such as: Regulations or public rules that the firm must comply; industry structure, for example, the existence of a lead firm; capital markets that might limit potential configurations; technology dynamics; business dynamics, like the existence of cyclical dynamics; and customer preferences that make demand for fashion uncertain and volatile.

Step 4: Mapping the Internal Capabilities

The internal capabilities of the product development systems, the production system and the distribution systems have to be mapped.

Step 5: Prescription of the Value Network Architecture

Following are some rules that can be used in order to select prescriptions for strategic configuration variables based on the strategic priorities of the firm and its internal and external constraints.

Rule 1: Strategy and Supply-Chain Architecture

If the strategy is to compete on innovation, then the rate of product change must be high (cases B or D), and if strategy did not ask for high service level (case D) the network should either provide quick make to order or keep some inventory centrally at the distribution centre as is the case in fast fashion.

If strategy is oriented to compete in service then (cases C or B) safety stocks are necessary, the amount being conditioned by the risk of obsolescence. For a strategy oriented to compete on cost, (applicable only if products are stable and service level is not a main objective) service would be done from safety stocks carried centrally as finished goods or raw materials depending on the cost.

Rule 2: Product Demand and Supply-Chain Architecture

- The SC is lean if waste has been eliminated (Ohno 1988). The SC is agile if it has the capacity to match supply with highly variable demand. Both concepts are not exclusive and could be complementary (leagile).
- For predictable demands and long lead times select (A). The supply network should be engineered according to lean principles. In fashion this scheme is only applicable to basic goods. The right supply chain is push oriented.
- For unpredictable demands and short lead times select (D). The best possibility is to manufacture in proximity and use numerous flexible workshops to absorb the demand fluctuations, this is the concept of pull as implemented by Zara.
- For predictable demands and short lead times select (C). It is the situation of Procter&Gamble and Wal-Mart using VMI (vendor-managed inventory).
- For unpredictable demands but long lead times select (B). The best approach is to keep inventory in a generic form and assemble on demand. This is a push/pull hybrid scheme where lean methods are applied upstream the decoupling point (the generic inventory) and agile methods downstream of the generic inventory. This scheme is used quite often in fashion, where un-dyed yarn and greige fabrics are carried out as generic and sourced from a push-efficient supply chain to reduce the effect of demand variability and after this point the chain is designed according to the agility concept.

Table 5.3 Linking strategy with a potential supply chain architecture (adapted from Diaz 2005)

	Rate of Product Change	Required Service Level	Description
Case A	Slow	Low	Some safety stocks carried centrally as finished goods or raw materials depending on value of the items
Case B	Fast	High	Trade-off between cost of obsolescence and cost of lost sales
Case C	Slow	High	Safety stock level high and distributed
Case D	Fast	Low	Produce to order or carry limited inventory centrally

Table 5.4 Linking product demand with a potential supply chain architecture (adapted from Christopher 2006)

	Demand variability	Replenishment lead times	Description
Case A	Low	Long lead time (months)	Lean: Make or source ahead of demand in the most efficient way
Case B	High	Long lead time (months)	Leagile: Carry generic inventory and assemble on demand.
Case C	Low	Short lead time (days)	Lean continuous replenishment
Case D	High	Short lead time (days)	Agile

Rule 3: Product Characteristics and Supply-Chain Architecture

This rule (Table 5.5) compares functional products (stable demand, low margin, high efficiency) with innovative products (high margin, less responsiveness).

Rule 4: Product Variety and Production Sites

This rule (Table 5.6) distinguishes two sources for variety: production-dominant variety and mediation-dominant variety. The first affects the production costs but not directly the consumer choice. The second is introduced to provide more choice to the consumer and affects little the direct production costs. The main lesson is that proximity enables real advantage in terms of mediation variety.

Table 5.5 Linking product characteristics with a potential supply-chain architecture

Product characteristics	Nature of Demand	
	Functional	Innovative
Product life cycle	More than 2 years	3 months to 1 year
Contribution to margin	5–20%	20–60%
Product variety	Low (10 to 20 variants per category)	High (often millions of variants per category)
Average error in forecast when production is committed	10%	40 to 100%
Average stock out rate	1–2%	10 to 40%
Average markdown as percentage of price	0%	10 to 25%
Lead time for made-to-order	6 month to 1 year	1 day to 2 weeks

Table 5.6 Linking strategy with a potential supply chain architecture (adapted from Diaz 2005)

Scale economies	Production location	Description
Small	Far	Low production and mediation variety
Large	Far	High production variety, low mediation variety
Small	Close	Low production variety, high mediation variety
Large	Close	High production and mediation variety

5.3 Modelling Textile Networks

Michael Weiß

Abstract Europe's textile and clothing companies face strong and growing international competition. To survive and thrive companies have to build new types of production and organisational networks like the 'extended smart garment organisation' (xSGO). This concept has been developed in the European research project LEAPFROG, with at its core the concept of smart organisations, which offer the companies additional possibilities to improve their competitiveness. The 'smart network modelling' method supports the description of organisations that incorporate the idea of the Smart Organisation. The structure of this modelling method and first-hand practical experiences are the main topics of this section.

5.3.1 Textile Industry and Textile Networks

The textile and clothing industry has a long tradition of networking. The value chain starting from fibre production up to garment or technical textile manufacture consists of many steps usually performed by individual companies, typically SMEs, which need to network with each other. Figure 5.1 in Sect. 5.1 (see also Fischer and Rehm 2005) demonstrates the complexity and the dependencies within the textile production chain.

The rapid development of information and communication technologies in the last decade enables new opportunities in this digital age but also frequently requires changes in the structure of organisations and networks. According to Filos (Filos 2006) the digital age is characterised by increased networking in a global economy, a new perception of value and intangible assets that emerge as an important source of economic value creation. In recent years new concepts for collaborative networking have been developed to exploit the various opportunities of the digital age. Camarinha-Matos and Afsarmanesh (2004) identified a large variety of collaborative network concepts from the virtual enterprise to the agile shop floor. Of particular importance are the concepts of Extended enterprise, virtual organisation, dynamic virtual organisation and virtual organisation breeding environment. For these concepts various approaches exist but no clear favourite has emerged so far. In the following, a short overview of the more sophisticated networking concepts will be presented.

The concept extended enterprise describes the extension of an organisation with functionalities provided by suppliers. Kalakota and Robinson (2000) focused on on-line business processes with a shared information infrastructure in a multi-enterprise supply chain as constituent element. For Michelini and Razzoli (2005) codesigning, comanufacturing, comarketing, etc. are the opportunities of a shared infrastructure resulting from an alliance of partners called extended enterprise. According to Camarinha-Matos and Afsarmanesh (2004) a dominant enterprise extends its boundaries to form an extended enterprise, which describes a specific type of a virtual organisation.

One early definition of virtual organisation by Byrne (1993) is that of an enterprise that marshals more resources than it currently has on its own, using collaborations both inside and outside of its boundaries. Another definition by Bullinger (1995) describes a virtual organisation as temporary horizontal and/or vertical cross-site cooperation between different companies, which organises the flow of activities based on efficiency aspects and not on organisational affiliation and also presenting itself to the customer as one unit. Camarinha-Matos and Afsarmanesh (2004) skips the idea of one face to the customer in their definition, which describes a virtual organisation as s set of (legally) independent organisations that share resources and skills to achieve a mission/goal.

Virtual organisations, which are established in a short time to respond to a market opportunity and have a short life-time, are dynamic virtual organisations following the definition of Camarinha-Matos and Afsarmanesh (2004). The European research project ECOLEAD (ECOLEAD 2006) refines this definition and states the necessity of a virtual organisation breeding environment to quickly assemble enterprises to a business entity.

Ellmann and Eschenbaecher (2005) define a virtual organisation breeding environment as a cluster or pool of potential partners with the ability and the will to cooperate and are therefore crucial to virtual organisations. Camarinha-Matos and Afsarmanesh (2004) refine this definition by describing the necessity of long-term cooperation agreements, interoperable infrastructure and the availability of a broker, normally the partner identifying the business opportunity, for forming a virtual organisation.

All these sophisticated concepts are concentrating on organisational or ICT aspects of cooperation extensively neglecting the intangible asset knowledge, which is a core value for the information society and the digital age.

Therefore (Filos and Banahan 2001) identified new important characteristics for networking based on the term ‘smart’ (e.g. smart resources or smart competencies) for successful collaborative networking leading to the new concept smart organisation. The constituent elements of a smart organisation are ‘knowledge networking’, ‘organisational networking’ and ‘ICT networking’ (see Fig.5.7).

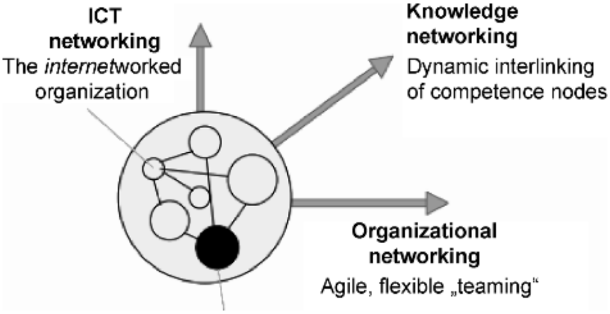

Fig. 5.7 Smart organisations are networked in three dimensions (Filos 2006)

Filos (2006) defines the term ‘knowledge networking’ as the capability to use external knowledge and the continuous and dynamic knowledge interaction with partners. He calls this knowledge handling, according to the linking of information in the internet, ‘knowledge hyperlinking’. The term ‘organisational networking’, also called ‘organisational teaming’, describes organisations, which are able to conceive, shape and sustain a wide variety of collaborative partnerships. The last term ‘ICT networking’ or ‘ICT-enabled virtuality’ depicts ICT architectures that are able to support the organisational structures and the knowledge exchange.

The smart organisation is the core concept of the ‘extended smart garment organisation’ (xSGO) developed in the framework of the European research project LEAPFROG (http://www.leapfrog-eu.org). In Sect. 5.2 the xSGO and additional background information about networking has been presented. The modelling of textile networks with the ‘smart network modelling’ method presented in this section offer the possibility to describe organisations following the three constituent elements of the smart organisation.

5.3.2 Modelling Networks

What is the purpose of modelling? This is always the first question you have to deal with when modelling, which Mulligan and Wainwright (2004) tried to answer. They identified the following purposes of modelling:

- as an aid to research;
- as a tool for understanding;
- as a tool for simulation and prediction;
- as a virtual laboratory;
- as an integrator within and between disciplines;
- as a research product; or
- as a means of communicating science and the results of science.

Holt (2004) found different answers to this question. According to him, modelling is an instrument to cope with the complexity of systems. It can assist the communication by offering a common language and common understanding of system elements. It also helps to understand the systems and its behaviour. According to Kay (1996, p. 19), the usual purpose of modelling is not to make predictions, but to enhance our understanding of complex systems. Such universal answers to the question of ‘why modelling?’ are not satisfactory to the practitioner. Therefore an individual answer for the ‘smart network modelling’ method has to be given.

First, ‘smart network modelling’ should provide a common basis for discussing organisations within a smart organisation context. This basis includes a common language, a common mindset and a common understanding of the principal relation and activities in the organisation. The modelling is also a solution for the problem described by Abdullah (2004):

> “It is very difficult for the human mind to be able to capture features of a system as a mental model and then convey those features verbally. The human mind often works better with a visual representation.”

Beside this more general purpose of ‘smart network modelling’ the modelling should assist the following four topics:

- analysis of networks;
- design of networks;
- coordination of networks; and
- design of collaboration systems.

The modelling should enable the analysis of organisations, e.g. by providing the possibility to learn about the current structure and to compare it with the target structure of organisations. Another analysis aspect should be the performance of organisations. Are there any media breaks? Are there any activities, which could be eliminated by restructuring the organisation, e.g. activities to externalise knowledge in one company and a corresponding activity to internalise it again in another company could be replaced by a socialisation activity with reduced risk of misunderstandings and lack of information? Another analysis aspect supported is the completeness of the organisation model. Are all necessary knowledge domains really covered? Are there any activities missing? However, the analysis of ‘smart network modelling’ does not cover the simulation of business activities. The models are not intended to give any information about the time behaviour.

The first step of cooperation is the design of the network covering the flow of activities, the flow of information and the provided knowledge. The modelling should be an instrument for discussing, designing and adjusting the structures of the aspired network, taking into consideration the individual goals of the network. Various variants of the targeted network structure can be analysed and discussed.

This analysis of design variants of the network can be performed regularly or event-based as an instrument for the coordination of the network. Changing requirements of the environment very often result in the necessity to change the structure of the network to cope with the new situation. Situations like a network partner leaving the network become more manageable. The effects can be easier to identify and appropriate measures can be initiated.

A further, ambitious goal of ‘smart network modelling’ is to be the first modelling level of the approach ‘model-driven application development’ for the configuration of collaborative systems developed in the European research project AVALON, which is similar to the model-driven architecture (Miller and Mukerji 2003). The ‘smart network modelling’ represents the computational independent model, which will be transformed via a platform-independent model and a platform specific model to a network specific configuration for a collaborative system, providing a tailor-made solution covering all the specific needs of the targeted network.

5.3.3 Smart Network Modelling

'Smart network modelling' allows the description of organisations, which could be a hierarchical entity but also a network, following the idea of smart organisations, thus meaning a holistic view on organisation, knowledge and ICT. The modelling is targeted at individuals that are able to influence the structure and design of organisations that could be, for example, the management of a company, an employee of the organisational development department, a manager of a department or a management consultant. With this basic condition in mind the following modelling structure has been developed.

The core elements of 'smart network modelling' are three dependent basic model types called 'business compendium', 'Structure Diagram' and 'activity diagram'. The 'business compendium' describes the various business activities and their relations. This model type defines the setting as well as the context in which the 'smart network modelling' will be performed. The 'structure diagram' illustrates the topology of the organisation, e.g. organisational chart or ICT architecture, within the settings and context outlined in the 'business compendium diagram'. Finally, the 'activity diagram' defines the processes and activities performed in the defined setting and context with the help of the topology of the organisation. For the 'structure diagram' and the 'activity diagram' three views, corresponding to the three constituent elements of the smart organisation, are available. These three views are called the 'organisational layer', 'knowledge layer' and 'ICT layer'. Figure 5.8 demonstrates the structure described above.

The core element of the 'business compendium' is the 'business activity' representing business processes. This element is extended by other elements for identi-

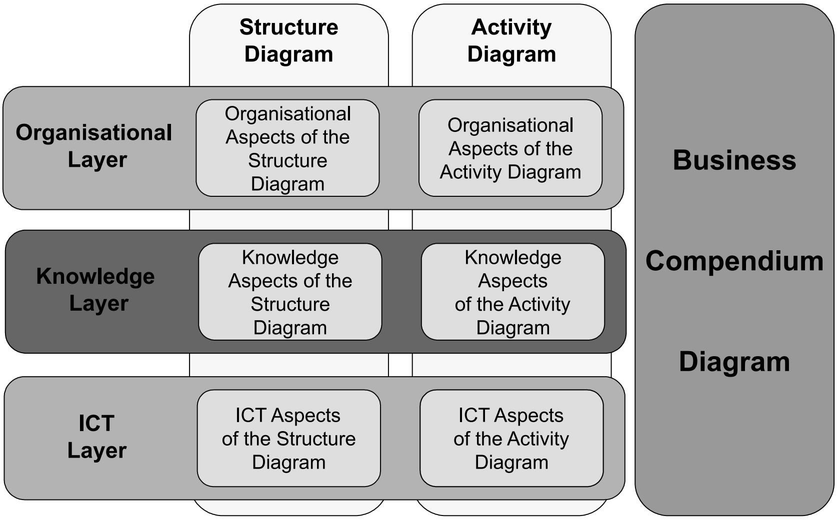

Fig. 5.8 Structure of the 'smart network modelling' method

fying individual goals, groupings of 'business activities' for special purposes and alignments of 'business activities' to the individual needs of customers.

The 'organisational layer' of the 'structure diagram' presents a view on the topology of the organisation focusing on the organisational aspects. It allows hierarchical organisational structures and non-hierarchical organisational structures to be modelled like teams. The same type of view is also available for the 'activity diagram'. In this view the flow of activities and the organisational responsibilities as well as the required technical resources can be described.

The main difference of the smart organisation from other networking concepts is the consistent integration of knowledge management. This important issue is realised in 'smart network modelling' with the view 'knowledge layer'. This view identifies in the 'structure diagram' the various knowledge domains. It allows detection of the development potential available in the organisation, which means to evolve from an available knowledge domain to a core competence from the organisation. In the digital age knowledge and information derived from this knowledge is a valuable resource that needs to be protected. Activities of protecting and conserving the knowledge are also part of this view in the 'structure diagram'. In the 'activity diagram' the link from the identified knowledge domains to the individual activities is established. This demand of knowledge has to be covered by people that are also assigned to the activities. It therefore describes the generation and exploitation of knowledge in the organisation.

The last view 'ICT layer' deals with the information and communication systems supporting the activities and the knowledge management. In the 'structure diagram' the view explains the architecture of the information and communication systems as well as the principal interfaces between the individual systems. These systems satisfy the information and communication demand of the individual activities described in the 'activity diagram'.

This 'smart network modelling' method has been realised with the software tool generic modelling environment (GME) (Ledeczi 2001), developed at the Institute for Software Integrated Systems at Vanderbilt University in Nashville (Tennessee, USA). GME is based on a concept that is similar to the meta object facility (MOF) (OMG 2006), developed by the Object Management Group (OMG). This software tool allows graphically defining the run-time and build-time modelling rules and to interpret them enforcing them during modelling. The rule set for the 'smart network modelling' method was complemented by a modelling style guide dealing with run-time rules not supported by GME.

5.3.4 Experiences with Smart Network Modelling

The 'smart network modelling' rule set was used to visualise typical network situations in the textile and clothing industry as well as new organisational and product innovations. The technical and industrial partner of the LEAPFROG project, in close cooperation with the scientific partners and the project AVALON, elaborated models for:

- garment-product development;
- a tracking system in a made-to-measure environment;
- organisational innovation ‘quality partnership’; and finally
- product innovation ‘SMA motorcycle helmet’ (together with the project AVALON).

The experiences gained with modelling these networks during the LEAPFROG project will be explained in the following.

Garment-product development is one of the core business activities of the clothing industry. It consists of structured and ad hoc sequences of activities. Also, many different players (internal as well as external) are involved. Therefore, it is a challenging task to organise this business activity in a smart way.

The model of the garment-product development is based on the six-phase Apparel Industry Product Development Process presented in the article of May-Plumle and Little (1998). This model has to be extended and adapted to reflect the idea of ‘smart organisations’. Core aspects concerning organisational, knowledge and ICT aspects are missing in the original model.

During the project LEAPFROG, the model was re-structured to fit the structure of the ‘smart network modelling’ method explained above. Missing or incomplete information, e.g. organisational responsibilities, involved ICT systems or the necessary knowledge domains, have been elaborated by industrial and technology partners with long experience in garment development. This additional information was integrated into the smart network model of the garment-product development.

The most difficult tasks in modelling the garment-product development were the identification of the involved knowledge domains and the handling of this knowledge. Many companies were not aware of the extent of knowledge required for product development. Knowledge with technical background like knowledge about marker making was easier for them to identify than the more abstract but also very important knowledge about interpretation of market analysis. The modelling also created the awareness of networking due to the strong dependencies on many other partners, e.g. market analysis or fabrics, even if the core activities are performed within one company.

The next network described with the ‘smart network modelling’ method was the production network of a made-to-measure Internet mail order shop, see Fig. 5.9 for the first steps of the performed business activities. In this network the customer is directly involved in the configuration and sizing of its ordered shirt. The communication between all network actors is performed via Internet. This puts an emphasis on the ICT systems. But due to direct the involvement of the customer in the design of the shirt, non-rational aspects play an important part in the business activity. The emotional link from the customer to its shirt requires a different kind of knowledge than standard mail order. The advantage of such an emotional link is a strongly reduced return rate with about 5% for made-to-

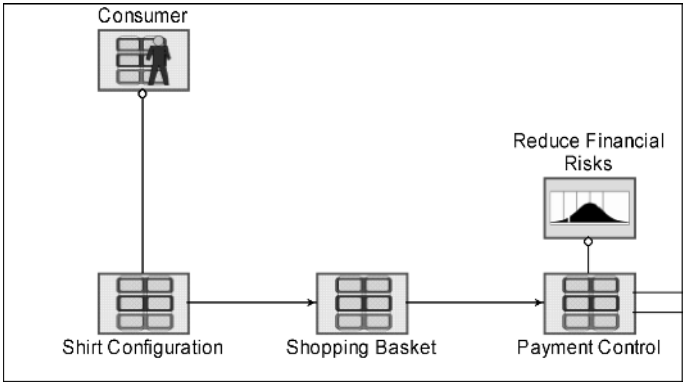

Fig. 5.9 Excerpt of the business compendium of a made-to-measure internet shop

measure shirts in contrast to up to 40% for standard products. To strengthen this link a constant feedback about the status of its personal product was given.

The ‘smart network modelling’ method was used to describe this ICT-focused production network. For this special network a more detailed description, e.g. more details about interfacing, of the ICT architecture would be useful but the available modelling elements are sufficient to have a general impression of the involved ICT systems. The ‘knowledge layer’ enabled the identification of suitable activities to integrate additional knowledge domains into the ICT systems thus improving the comfort of customers and creating positive emotions, with the Internet shopping system as the gateway to the production network.

The idea of the organisational innovation ‘quality partnership’ was to reduce the lead time of the production network by minimising quality tests. To reach this goal a series of activities had to be performed preparing the network participants for eliminating double testing activities.

The first and very important activity to reach this goal was to harmonise the testing systems between the network partners to obtain comparable results. All testing systems in the network had to be reviewed and standardised concerning testing environment and testing method. The second step was to create a common mindset in the whole network about quality of textiles. Extensive testing was performed to validate the new production and testing process. If the validation process is successful the suppliers in the network will be validated for direct delivery (see Fig. 5.10) and can change the delivery processes accordingly, including the integration of the suppliers in the development process, skipping unnecessary testing.

The organisational changes and training of all involved partners could be represented by the ‘smart network modelling’ method. One core aspect, the harmonisation of the testing activities could be described only insufficiently due to the technical nature of this subject. The principal idea of this innovation could be transferred via ‘smart network modelling’. Also the increased demand of knowledge and information for the ‘quality partnership’ is visible.

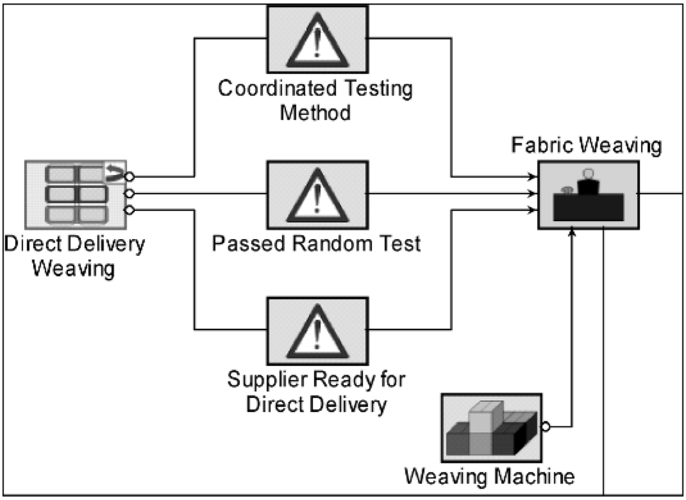

Fig. 5.10 Excerpt of the pre-requisites for direct delivery ('organisational layer') in a weaving company

Finally, a production network for a new-product innovation, involving shape-memory alloys, was modelled. The network consists of a bicycle-helmet producer, a weaving company and a wire producer forming a cross-sectoral cooperation. This production network requires extensive use of knowledge due to the innovative material (Ni-Ti). In the European research project AVALON (http://www.avalon-eu.org) an attempt was made to identify the total cost of ownership (TCO) of this production network based on 'smart network modelling'. In the TCO analysis the costs for establishing the production network or for ending the cooperation were not considered, i.e. the TCO were mainly reduced to the transaction costs. In a first step the production network was modelled. The used modelling objects were analysed and the corresponding TCO cost categories assigned to them. For each object the costs were calculated or, if not possible, estimated. Especially for the objects of the 'knowledge layer' it was difficult to determine the cost due to missing comprehensible information. Many information systems are not prepared to deliver this type of information.

The 'smart network modelling' method was originally not designed to support TCO but worked well for identifying the most important cost drivers. Beside the TCO aspects the modelling was able to describe the cross-sectoral production network and also the extensive knowledge demand could be represented.

5.3.5 Summary

The experiences gathered by industrial, technical and scientific partners in the LEAPFROG project proved that the aim of modelling could be reached by the 'smart network modelling' method. It is a useful tool for analysing, designing and coordinating organisations considering the concept of the Smart Organisation. The 'organisational layer', 'knowledge layer' and 'ICT layer' provide a comprehensive view, reducing the complexity of the overall systems to manageable parts thus allowing a better understanding of the system. The layer structure gives the organisation the flexibility and agility to become smart.

The support of 'smart network modelling' by GME and the possibility to store the models in a machine-readable format (XML) is necessary for the 'smart network modelling' method to be part of the approach 'model-driven application development' for the configuration of collaborative systems. It enables the automatic transformation of a computational independent model via a platform-independent model to a platform-specific model.

At the moment the analysis, design and coordination of organisations is made manually. In the future, due to the machine-readable format, these tasks could be supported or performed by information systems evaluating the models and proposing design changes.

5.4 A Knowledge-Exchange Infrastructure to Support Extended Smart Garment Organisations

Piero De Sabbata, Nicola Gessa, Gianluca D'Agosta, Matteo Busanelli, Cristiano Novelli

Abstract In this section the authors present the activities of the LEAPFROG project aiming at the definition of a knowledge-based exchange infrastructure, to improve ICT interoperability and to enable the emergence of a new paradigm for e-business in the textile-clothing value chain: the extended smart garment organisation (xSGO) model. This work exploited mainly the experience and results obtained in preceding projects in the textile-clothing sector, but produced results that can be applied also in other production sectors. The key points of our work have been the integration of technological and organisational aspects building enterprise networks and the creation of open communities that exploit standardisation mechanisms. The result has been the definition of the basic building blocks for the knowledge-exchange infrastructure (KEI) and the development upon them of a set of tools that simplify the definition of e-business collaboration among enterprises.

5.4.1 Introduction

In this section we focus our attention on the aspects related to the implementation of an extended smart garment organisation (xSGO), as defined in (LEAPFROG

2005), that is considered as the organisational paradigm that should be built in parallel with the introduction of new production concepts, methodologies and technologies.

The xSGO is characterised along three dimensions: the organisational/procedural dimension, the knowledge/semantic dimension and the technological/ICT dimension. Our focus, in this chapter, is on the ICT aspects related with organisational aspects of manufacturing networks, especially clusters of enterprises, and, among them, clusters without a leader 'dominant' enough to impose its internal organisational and technical solutions on its partners. The crucial point is that adequate ICT infrastructures and the related organisational procedures must facilitate the flows of data and knowledge that have to be exchanged between different firms. This is becoming crucial also in order to assure the governance of the processes of outsourcing and delocalisation.

Concerning the development of ICT solutions, we observe some relevant specificities in the textile-clothing industry, probably related to the large presence of small and medium-sized enterprises (SMEs) that need to collaborate extensively among themselves as well as with larger enterprises:

- difficulty to establish/understand collaboration processes and the related ICT tools (due also to absent or poor organisational and technical skills inside the companies) that result in a high barrier for the firms to start business collaborations;
- the lack of a critical mass of participants limits the benefits perceived by the enterprises;
- long time to develop and test a solution before the release for real use;
- costly scaling due to the absence of a common understanding and background between different solution providers and organisations, even when implementing the same processes.

To tackle these problems in other industrial sectors, for example the automotive or chemical sector, there has been an effort in order to establish sectoral standards able to depict the procedural and technical aspects of the intercompany collaborations.

Several actors in the textile and clothing industry have proposed some standardisation results (TexSpin 2004; TexWeave 2006; Gessa 2003; De Sabbata 2008; eBiz TCF Project 2008) but they suffer from a poor adoption (the benefits are tangible only when a critical mass of adopters is reached) as well as from the fragmentation in small and separate communities with very specific needs and different technical solutions. Thus, what emerges is the combination between technological and organisational problems.

Efforts are underway to achieve interoperability through standardisation (CEN/ISSS 2008), even with specific sectorial initiatives like the eBIZ-TCF project (De Sabbata 2008), in parallel, on the side of ICT research, projects in the enterprise interoperability field (Athena 2005), (Enterprise Interoperability Research Roadmap 2006) attempt to improve the capacity of the systems to interoperate and to answer to these problems through semantic tools and services.

It is already known that ICT standardisation processes (Jakobs 2004; Soderstrom 2004; De Sabbata 2005) do not meet the needs of the industry, especially of SMEs, at least in two key aspects: time to produce standard specification (the process of establishing a standard is too lengthy) and resources needed to participate in standardisation processes and to implement the outcomes (often very complex). Moreover, a third aspect is that the outcomes of standardisation processes are not flexible enough to support every specific process (Euzenat 2001).

On the other hand the novel approach based on ontologies and semantic technologies requires skills that are not easily available to the industry and lack a common background and guidance so that real interoperability between owners of different solutions appears poorly scalable.

This section presents a way to pursue the following two objectives:

- Reduction of misalignment between systems and organisations through a simple and automatically supported way to model the collaboration processes and the related ICT support.
- Fast setup of collaborative procedures and definition of customised data models starting from an existing standardised background through semantic tools.

The outcome of this work has been defined as a knowledge-exchange infrastructure (KEI) and has been described in (LEAPFROG 2007a, 2007b). Its purpose is to support the creation of 'open communities' of collaborating firms without being constrained by a proprietary solution.

The first part of the section will address the technological framework and the related state-of-the-art; the second part is dedicated to a more detailed description of the tools and components of the framework.

5.4.2 State-of-the-Art

In the analysis of the state-of-the-art of models and solutions, we identified, first of all, the fundamental aspects to consider building a complete and successful interoperability framework (Dogac 2001; Medjahed 2003; Shim 2000). This analysis allowed us to clarify the complex scenario related to the world of interoperability solutions: on the one hand, we identified the abstract components that have to be part of the solution; on the other hand, we investigated existing solutions, the actors that provide them and their role.

Concerning the first point (the abstract components implementation) we can observe that, according to many definitions of the term 'interoperability', a solution must provide three different interoperability layers:

1. the definition of a syntax for information and data exchange in a business collaboration;
2. the definition of a common shared semantics related to the syntax;
3. the definition of business processes.

1. In order to define a proper syntax for information exchange, XML is the most popular standard in the definition of data formats for communication interchange between heterogeneous systems. XML syntax definition has been often bounded with the definition of standards (like eCO, cXML, UBL, and many others) that play a relevant role in the definition of a really usable and accepted interoperability framework.

There is a huge number of standards and standardisation initiatives. (XML applications and industry initiatives) provides just an idea of this wide and dynamic world. In any case standards are relevant for interoperability, but also difficult to manage (Soderstrom 2004; De Sabbata 2005) and often hard to match with specific needs of individual enterprises (Euzenat 2001). Our work has considered it fundamental to operate in synergy with proper standardisation initiatives, in order to bring out the framework definition and to define tools to exploit standard definition.

2. Syntax definition is not enough, however. Together with the syntax, a shared semantic view of the data must be defined. This means basically the definition in an ontology of a set of concepts/relationships that are associated with data formats in order to clarify the meaning and the use of the formats. Semantic modelling is strictly related with the vision of the Semantic Web, but can also prove useful in e-commerce scenarios (Choi 2006). Because of the different data formats, document structures and vocabularies of business terms adopted by each enterprise, the Semantic Web technologies are exploited to make two enterprises interoperable with each other adopting mapping mechanisms (via internal or outsourced services) to compose semantic differences. ebBP (2006) presents a list of the main activities in this field. What is important to highlight is that, considering the development of the Semantic Web technology, an interoperable framework can improve its exploitation providing a way to ease both its ‘comprehensibility’ and the mapping towards different systems. In this scenario, OWL represents the W3C recommendation for ontology definition.

3. Finally, the specification of an interoperability framework requires the definition of shared business processes upon which to exchange business documents. In (Dogac 2001; Medjahed 2003; Shim 2000) there is a comparison about the most relevant ones. What emerges is that the ebXML framework represents the most complete one. The ebXML approach for the definition of agreement between partners is considerably different from other initiatives since ebXML defines a clear process and modelling infrastructure for the definition of collaborative scenarios. This means that not only ebXML allows (as others platforms) to define standard business transactions that can be used as a reference by the actors of the sector, but allows also the enterprises to personalise and publish their own profiles in order to customise electronic exchange mechanisms (with all their characteristics) for their needs. In fact, often an ‘external’ definition of classic business scenario does not match either with the requirements or with the skills of the real partners that have to adopt them.

The previous analysis and considerations have strongly impacted on the definition of the framework developed in the LEAPFROG project (see Fig. 5.11) and resulted in the identification of the basic components that constitutes the proposed solution. These components will be explained in the next sections.

5.4.3 The Approach: The Knowledge-Exchange Infrastructure (KEI)

The extended smart garment organisation (xSGO) is a complex collaborative model for enabling textile and clothing companies to cooperate together in a common business scenario (LEAPFROG 2005).

This model intrinsically requires the involved companies to exchange knowledge or information among each other in a fast and efficient way, that should be based upon common standards: in other words, following the definition of the term ‘interoperability’ these industries should be able to ‘interoperate’ together.

But the interoperability capability of a network of companies does not guarantee the creation of an xSGO: in fact it covers only one of the three dimensions that characterise the xSGO, the technological/ICT dimension and does not apply to the others. In other words, the interoperability between cooperating companies is a requirement and is not in itself sufficient for the creation of an xSGO.

The first step to allow networked companies to become xSGOs is to facilitate the processes enabling industrial interoperability: a set of tools easy to use, flexible and able to include the future ICT developments and requirements from companies.

The analysis of the state-of-the-art, based on the interoperability requirement for an xSGO, suggests that:

- each identified aspect (syntax, semantic view and business process definition) can be approached separately finding an ‘ad hoc’ solution for a specific situation that does not involve the other two;
- separated approaches created, in the past, a large number of different standards, mainly based on XML dialects, for each different aspect (different languages for document syntax, different ontologies or non-compatible languages for business process description like BPEL and ebBP);
- a practical solution of the problem requires an integrated approach to the different aspects, a selection of specific languages and the creation of a common infrastructure that exploits the potential of each tool or language.

The way is to create an integrated framework, called knowledge-exchange infrastructure (KEI), able to support ICT and industry experts in implementing interoperability between partners, based on existing standards (when possible) and open to industrial requirements.

We started the KEI design with the identification of the active subjects in the actual e-business scenarios: from one side we have standardisation or ‘community-level’ initiatives, public bodies and research centres, on the other side manufacturers and solution providers. The design of the KEI (Fig. 5.11 gives an overall vision of the KEI) consists in a set of different layers, each of them providing different actors with different functionalities, that are used to create and to develop integrated and more complex tools.

The first two layers, 'core concepts' and 'tools and specification' are mainly constituted by the results of the work made by a generic public or community level entity, like the LEAPFROG Community, and concern the *specification phase* of the collaboration (for example the modelling of the collaboration or the creation of a common dictionary).

The other layers relate to the *operational and network setup phase* where industries and solution providers build up the business network and dynamically set up business collaborations by exchanging documents and using other features and services supported by the framework (i.e. automated mapping of different data formats or searching business partners, etc.).

Finally we defined the 'peer' level as an important support level for the business services and sector specific services layer defining, from the ICT point of view, the way to exchange information between networked industries.

The strong involvement of the firms is needed for requirements collection, optimised set up of the framework, but also for the dissemination and deployment of the results.

The core concepts layer includes all the basic components that play a central role in each framework activity and is defined in concert with the target users: it contains the 'common reference' elements like the dictionary or the ontology and represents a shared knowledge base that underlies each human community.

The tools and specification layer, on top of the core components layer, supports the community in the framework specification or maintenance phase. For example the business document specification component exploits the terms stored in the dictionary to define templates for business documents used in transactions, while

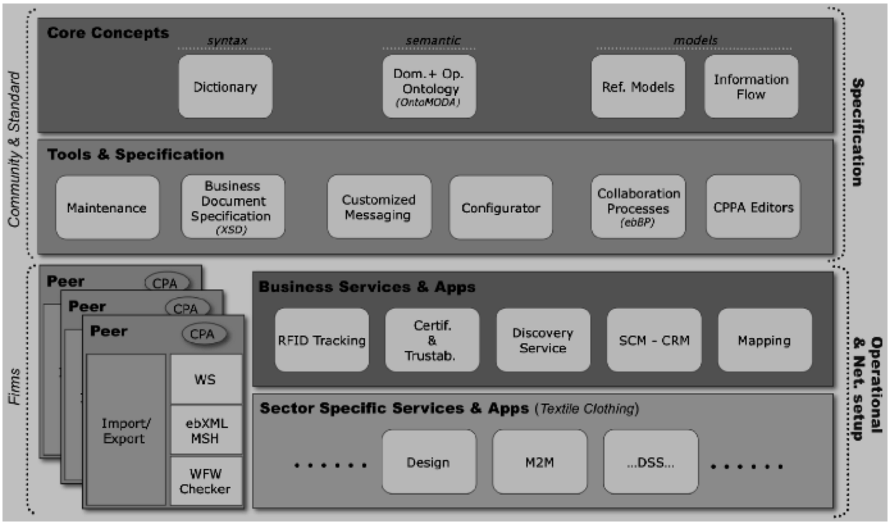

Fig. 5.11 Integration of semantics and syntax in the architecture

the maintenance tool allows the creation of new entries in the dictionary. The idea of this layer is to simplify drastically both the creation of new specifications (for example a new document model required in a specific business transaction between two companies) and the maintenance process that typically requires a lot of human effort.

The business services and applications layer represents a level of base services and applications directly or indirectly used by firms for real business activities. Some of these components (i.e. the configurator) are used only one time by the firms for setting up the business network, while some others (i.e. RFID tracking) are used daily in the operational phase. Most of these components are expected to be provided by software houses or by big companies. These tools are sector independent; in other words, they implement generic functionalities not tailored for a pecific business sector but useful in different areas. In some cases these components can be specialised or adapted for different sector requirements maintaining also a ‘general purpose’ design.

The last layer in order of specialisation is the sector specific services and applications layer that includes those components that provide specific services for the textile-clothing sector. All these components should easily interoperate with each other taking advantage from the three previous levels. As for the business service and applications components, these are expected to be provided by software houses or developed by the companies themselves, exploiting common standards and specifications.

In the overall KEI framework diagram we included also a peer component. This represents the architecture and the ICT infrastructure needed by an enterprise for setting up an effective communication with another partner without passing via a central node. As in a classic P2P scenario, the application plays both the client and server roles to send and receive business messages.

During the LEAPFROG project we focused our attention on the first two layers that represent the basis of the whole framework. In the next section a more detailed discussion of the realised components is provided.

5.4.4 The Components of the Framework

The development phase performed during the project resulted in a set of software components that represent the practical translation of the abstract model detailed in Sect. 5.4.3.

Within the project, the syntactical definition has exploited the experience obtained from earlier work. More specifically, the data formats for business messages is based upon a dictionary defined in the Moda-ML project (De Sabbata 2005; MODA-ML 2005) that comprises a wide set of documents and specifications tailored for the textile-clothing sector. This dictionary has been used in the TexWeave (TexWeave 2006) initiative and the successive eBIZ-TCF initiative that represent two efforts to produce a practical, formal and standardised set of data structures for the sector. Moreover, adopting the Moda-ML/TexWeave vocabulary we have also re-used and exploited all the tools available for its further development and maintenance (Gessa 2003), and not only the syntax. All these aspects represent a guarantee for the trustworthiness in the adoption of the document defined upon the Moda-ML/TexWeave vocabulary.

On the other hand, the problem of a clear definition of the semantic model, arises when we imagine a dynamic environment (like that studied in the LEAPFROG project) where we are continuously requested to manage new types of data flows or to improve the existing data models with others taken from new domains compared to those modelled in TexWeave. To facilitate comprehension and improvement of the data models we developed a set of OWL ontologies that describe the concepts and the relationships that characterise the wide set of terms contained in the vocabulary. In this way we can describe the semantic model of the data format.

Moreover, the interconnection between the set of the TexWeave terms and their ontology description required the definition of a proper architecture to maintain all types of information linked together, as for example in the case of maintaining the alignment between the ontologies and the successive versions developed by Moda-ML. The definition of such architecture has also considered the different characteristics of the different parts of the information collected.

As depicted in Fig. 5.12, the semantic description of the information is defined based on:

- Moda-ML dictionary: this is a dictionary of business terms on which the TexWeave standardisation specifications were based.
- The OntoMODA, that is mainly composed of two subontologies: *dynamic ontology (DO), static ontology (SO).*
- Annotated XML schemas and type libraries: this is a library of XS types and a set of XS documents annotated with the concepts defined in OntoMODA. The Moda-ML Dictionary is the basic component upon which we base the whole syntactic and semantic description.

We decided to divide the OntoMODA ontology in two different subontologies in order to respond to two different requirements: on the one hand, the fact that basic knowledge related to the sector knowledge does not change substantially over time: concepts like '*fabric*', '*machine*', and '*yarn*' always remain the same. These kinds of concepts are those that constitute the 'static ontology'; the static ontology is manually built by domain experts. To improve usability and maintenance, the static ontology is modular and therefore composed of several subontologies, each of which addresses different modelling and meta-modelling aspects (i.e. the real sector knowledge, the ISO11179 standard, the XML schema meta-modelling).

On the other hand, the information and the definition of the practical data formats are much more subject to change over time (for example to comply with new standardised releases). Then, the semantic description of this information should change over time following the modification of data formats. This semantic description is maintained in the '*dynamic ontology*': it models the XML components (types, elements and attributes) used as interchange data format in e-business transactions. This 'dynamic ontology' is generated in an automatic manner from

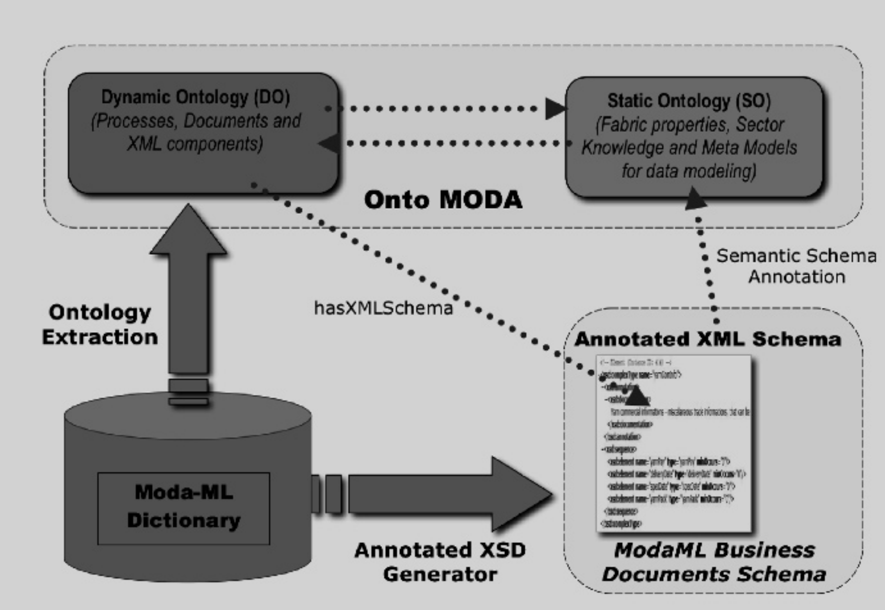

Fig. 5.12 Integration of semantics and syntax in the architecture

the set of terms contained in the ModaML Dictionary using automatic application and is split into three subontologies concerning business documents (like order, invoice, etc.), business processes (i.e. fabric production, supplying etc.) and the XML schema components defined in the real XML schema files.

The static and dynamic ontologies are bi-directionally interconnected: in this way each abstract concept modelled in the static ontology is connected with the ontological description of the representation mechanisms adopted to exchange the information (i.e. the XSD components – element or type – used for its representation), and *vice versa*. These connections are modelled using OWL properties.

We also implemented connections between the Moda-ML documents (the XSD templates built upon the Moda-ML dictionary) and OntoMODA. In this way it is possible to provide for each document a semantic description of the meaning of each element or type. This interconnection is implemented adopting the W3C recommendation for semantic annotation that allows adding the semantic information to XML Schema documents.

OntoMODA represents a great knowledge source that could be used for documentation purposes. Thanks to the textual description of many concepts it can offer interesting information useful for people who need to know product definitions, industrial processes and fabric properties.

In order to search and read information through the OWL ontology we developed a web application named ontology explorer. The tool lets the user surf the entire OntoMODA, starting from the taxonomy and picking up from it the desired concepts to see more detailed information through appropriate panels.

There are many tools to edit and browse ontology. Protégé is one of the most used, but there are many others. On the other hand, our aim is to simplify the operation of ontology browsing.

The ontology explorer allows the user to navigate ontologies, in a simple way (it is not strictly related to the OntoMODA ontology and it can show all the online ontologies written in OWL language) and to find concepts and information. Currently, all the tools that manage ontologies are really hard to use and to understand: industrial experts could hardly be expected to be so skilled in computer science or in ontology development to use these tools. Then, a relevant problem in developing an ontology for a classical industrial sector, like textile-clothing, is to create user-friendly tools: the ontology explorer is a configurable web tool that is mainly oriented to the domain expert rather than to the ontology expert or developer. It provides more and better functionalities than other tools dedicated to the same purpose. To enable these functionalities, the ontology explorer is designed to be intuitive to use (also for the inexperienced user) and many visualisation and navigation configuration alternatives are available to the user. It also implements dynamic components that respond to user input, thus enhancing interactivity.

In order to support the whole process of establishing business agreements, we also developed a set of applications that allow the enterprises to produce standardised documents representing business profiles (collaboration profile protocol, CPP) and agreements (collaboration profile agreement, CPA) following the ebXML specification (already known as ISO TS 15000). In fact, once data formats are defined and clearly described using both the TexWeave dictionary components and the OntoMODA ontology, these formats must be contextualised in a digital data-exchange scenario.

The CP-NET (Collaboration Protocol – Networking Enterprises Technology) application set enables enterprises that want to cooperate through a collaborative ebXML-based framework, to define and perform business collaborations.

ebXML business collaborations are based on profiles and agreements, and these concepts are defined and regulated by the ebXML Collaboration Protocol Profile and Agreement (ebCPPA) specification (CPPA 2007).

To manage profiles and agreement following the ebXML specification CP-NET provides two web applications: the CPP Editor and the CPA Match Maker.

With the CPP Editor an enterprise can create and modify its own CPPs (Collaboration Protocol Profile), required to set up the collaboration with other industrial partners. The application reduces the risk of errors while performing this operation, and is based on a simple interface supported by an on-line help function. In fact currently the CPPs are created manually, directly writing the XML, because no tool exists that provides a user-friendly interface to create CPPs. With the CPP editor we want to close this gap, allowing a non-XML expert to write a correct CPP.

Once the CPPs are available, currently the two CPPs are manually compared to identify both the possible problems and the agreements: the problems are solved in a direct contact by the persons involved, using phone or fax. At the end of the process nowadays one of the partners must write down all the defined agreements in an XML-structured document that follows the ebXML specification. This document is the final CPA.

This process takes a lot of time, because the agreement process is, normally, not in real time: when a possible conflict arises during the CPP comparison, the CPA writer must contact the other party and negotiate the modifications.

The CPA MatchMaker aims to simplify this agreement definition process: with the CPA MatchMaker it is possible to build the Collaboration Protocol Agreements (CPA) for a number of enterprises, from two CPP Profiles. The CPA MatchMaker reduces the whole agreement process and the comparison time highlighting directly the conflicts between the two CPPs. At the end of the agreement process it writes down directly the CPA in the XML format.

5.4.5 Conclusion

The work presented in this section tackles the problems that arise when different and independent organisations attempt to collaborate in order to setup an xSGO. In particular, our analysis highlighted the difficulties of integrating existing ICT solutions, e-business standards and organisational aspects in enterprise network collaboration, especially in a sector with a prevalence of SMEs. This integration can prove to be a key point for the improvement of e-business collaboration.

For this purpose we propose the knowledge-exchange infrastructure (KEI), that has been designed as a conceptual framework that models, in different abstract layers, the components needed to build up an xSGO.

Some layers provide the basic functionalities of the framework itself. For these layers some tools have been developed to define/manage a shared syntax for data interchange, to build and maintain the common semantics for all the participants, to link these to the existing international e-business standardisation initiatives; some others aim at facilitating the companies in modelling their business processes in a way that is able to interact with existing company information systems; some other layers, finally, are just thought to contain the operative services that can be provided to each firm or group of firm for their daily work.

These layers are considered to address the needs of the different roles and expertise (for example interoperability experts and domain-specific solution experts rather than consultants or EDP personnel) that are involved to set up a collaboration between different organisations.

The abstract framework and its set of prototypical tools is a first attempt that needs further improvement and a more systematic approach to the aspects related to the different types of knowledge that are exchanged between companies.

The abstract framework and its set of tools represent an attempt to ease and improve the setup of xSGOs between enterprises. It exploits not only the definition of common data formats and business models, but also defines an underlying shared semantic layer to support a faster integration between heterogeneous systems.

In fact, nowadays there is a clear trend towards more ‘knowledge intensive’ exchanges between firms implementing innovative models of collaborations. The governance of such models and the knowledge management in terms, for example, of protection of the distinctive know-how will require an in-depth analysis of their effects on the ICT infrastructure and interorganisation interface.

5.5 Supply Chain Event Management Integrated Product Tracking and Tracing

Jens Fabian, Mirko Morgenstern

Abstract The tracing of product data along the value chain of a company's network is a more and more important task because of an increasingly complex organised manufacturing structure. The particular difficulty arises from the fact that the structure of the product data is potentially unknown, so it has to be adequately configurable and flexible. In addition, traced product data has to be compared with pre-defined set points to respond to deviations. This section presents the product tracking system developed within the LEAPFROG project.

5.5.1 Introduction

The tracing of product data along the value chain of a company's network is a more and more important task because of an increasingly complex organised manufacturing structure. The particular difficulty arises from the fact that the structure of the product data is potentially unknown, so it has to be adequately configurable and flexible. Within LEAPFROG a new product data tracking solution was developed. This solution is based on TXT e-solutions' SRM[2] collaborative platform TXTChain and is in particular designed with respect to the situation and the requirements of the textile and clothing industry.

5.5.2 Supply Chain Event Management and Supply Chain Management

The concept of supply chain management (SCM) describes the cross-company coordination of material and information flows along the entire value chain. This includes all processes starting at raw material purchasing, all producing stages of the value chain and finally the delivery of finished products to the customer. Just the coordination and optimisation of this business processes in today's global market has an enormous relevance and is often a key factor for the success of a company. According to Werner (2000) the main objective of SCM is "to do the right things at the right time". By optimising the effectiveness and efficiency of all business activities as well as the harmonisation of various factors, such as costs, time, quality and flexibility, there will be lower costs, shorter lead times and a better product quality and service. Figure 5.13 shows a typical value chain of a clothing manufacturer.

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[2] Supplier relationship management (SRM): A comprehensive approach to manage the company interactions with the organisations who supply goods and services for the company.

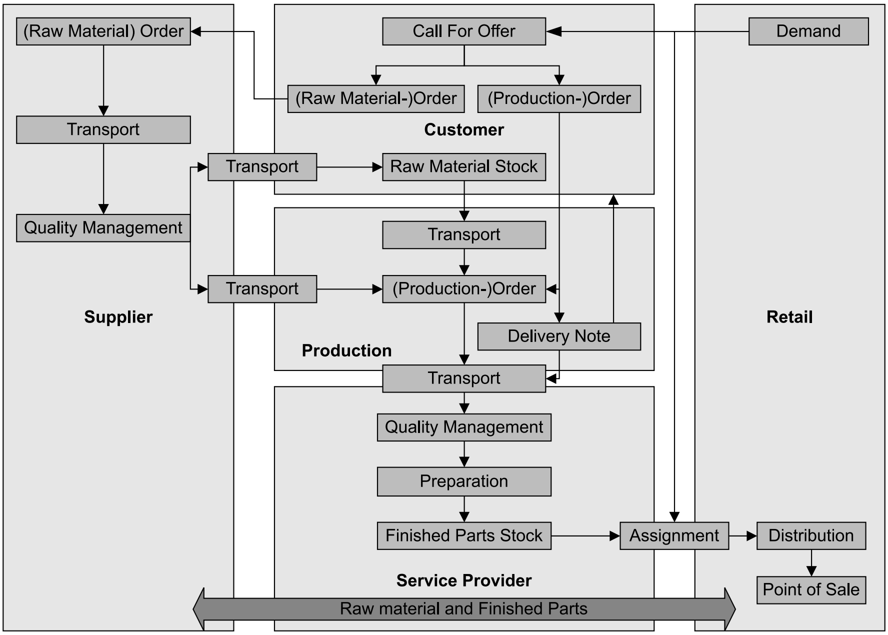

Fig. 5.13 Typical value chain of a clothing manufacturer

To provide the required information for such decisions, dedicated application software systems are needed. The main task of such software systems is to collect, process and provide all information about the processes in the value chain of a company.

An important concept of such systems is the supply chain event management (SCEM) which supervises all business processes, highlights critical issues or processes and informs defined users to react timely. This allows switching the daily business to a ‘management by exception’ business. So users are focused to those business processes that are running out of order. The parts of normal working processes are handled as automatically as possible. In fact, 80% of the business transactions work normally. The remaining 20% should be detected by SCEM systems.

In addition to the concept of SCM systems there are also SRM systems. SRM means supplier relationship management and describes a comprehensive approach to manage the company interactions with the organisations that supply goods and services to the company. SCM refers to the strategic planning and operational coordination of all value-chain activities and is primary focused to material and information flow. In this context SRM refers to the management of the relationships between all cooperating partners in a value chain of a company. SRM is therefore a part of SCM. Below, a summary of most important features of SCM and SRM systems is given.

- Sourcing and order management
  - *Call for offer* supports buyers and suppliers when negotiating supply relationships (price, delivery dates, terms of delivery, etc.).
  - *Order management* automates the management and approval of production and purchase orders. It supports order generation, as well as order confirmation, updating and tracking.
- Catalogue and document management
  - *Catalogue data management* allows suppliers to publish easily their catalogues in a shared electronic environment. The system acts as a translator between *suppliers'* and customers' master data. Customers can see product codes in the way that is most familiar to them.
  - *Electronic delivery notes and shipment orders* are generated and transmitted by the system. *Functions* are available for order confirmation and tracking, as well as for the supervision of transportation.
- Operations control and performance measurement
  - *Production progress monitoring* enables the monitoring of subcontracted work. Reports about production progress can be shared easily and viewed with the desired level of detail.
  - *Event management* helps users to intercept irregularities and critical situations before they may cause inefficiencies. The system automatically sends a notification when determined thresholds are crossed.
  - *Key performance indicators management (KPI)* allows users to attribute performance indicators to the activity of suppliers, subcontractors and logistic service providers and therefore to determine their reliability over time.
  - *Workflow management* associates flexible workflows to all the managed processes. Users are guided easily through a sequence of activities.

5.5.3 The Collaborative Platform TXTChain

TXTChain was selected as backbone system for the new product tracking system (PTS) by the LEAPFROG partners as it provides a variety of features for supply chain execution and supply chain event management. It is well established in textile and clothing industry and many other sectors, and was designed and developed within the European research project VISIT (project no. EP29817) between 1999 and 2001.

The web-based platform enables a consistent and coherent order processing and collaboration within complex supply networks. It can be connected directly to the companies' ERP[3] systems or accessed through a web front-end, allowing for seamless transactions between the participants across the supply chain. One important part of SCM is SCEM.

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[3] Enterprise resource planning (ERP): Application software to support the resource planning in companies.

The system was developed to improve communication between companies involved in international business processes. Today, it encompasses a number of industry-specific processes and provides functions tailored to user needs. The most heterogeneous user groups are supported, from the management down to operational staff. In today's globalised world, users can be located in almost any country around the world.

TXTChain starts where ERP systems end. Instead of building expensive 1:1 relationships and interfaces between each single system or company, the solution manages the networking of business partners. It is user-friendly and requires only minimal training, enables companies to negotiate volumes and deadlines as well as contractual aspects of a supply with suppliers and subcontractors.

On the other hand, this SCEM system provides subcontractors, suppliers and logistic service providers with a complete overview of the orders that concern them. They can supervise progress by flexibly setting updates on the status of orders, issue notifications and exchange messages and documents. Figure 5.14 shows important functions, which can realise the following benefits:

- improved transparency in the value chain;
- reduction of communication and response time;
- event manager provides immediate and accurate information on problems and allows an early error detection;
- reduction of delivery costs while using electronic packing lists and automatic generation of transport orders;
- improved process efficiency and flexibility because of direct electronic information exchange with business partners;
- improving the delivery level (delivery time, reliability, quality, flexibility);
- reduction of reserve capacity in production and logistics;
- elimination of the bullwhip effect.

For more information about TXTChain please look for TXTPerform at http://www.txtgroup.com.

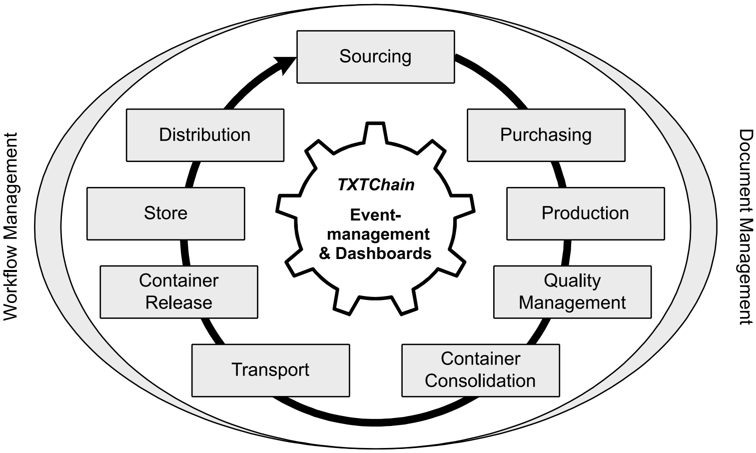

Fig. 5.14 Flow within TXTChain

5.5.4 Requirements for the Product Tracking System

The new product tracking system has to be an intercompany system. The main task of the system is the collection and retrieval of data of different actors in the value chain, and the production process of an order or a single good shall be seamlessly replicable. The tracking data have a potentially unknown structure and must be available to all participants based on their user rights. The data collection takes place in three different ways:

- ICT[4] systems (ERP, MES[5]);
- manual interaction;
- process integrated.

The fact that the structure of tracking data is potentially unknown arises from various operational requirements of each customer. Furthermore, several ICT systems of participants provide different information about the value chain. It is not possible to see which data should be traced in the future. Because of all these facts it is important that all parts of the PTS are high configurable.

Data can be collected on different levels like order, unit or item level and differs from business case to business case. So the main problem is, to trace potentially unknown data and share it with different actors in the value chain. Data to trace are for example:

- core logistic information (quantities and dates);
- production progress data;
- quality control data;
- transportation data.

Another important requirement to the system is the fact that the user of the system should be able to configure the data that he wants to trace by his own. Due to this fact the user interface for configuration has to be as simple as possible.

- Configurable data structures: Because of the fact that the structure of data to trace is potentially unknown it is necessary to use a flexible data store. The data structures, hereinafter referred to as templates, need to be fully configurable and have to work with different data types. An easy-to-use user interface is required to manage the templates.
- Data collection and data retrieval: For data collection and retrieval a flexible user interface is required that is based on a selected template. Furthermore, it has to have a variety of search and filter capabilities. Additionally, a flexible system interface is required in order to exchange data with third party system.

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[4] Information and communication technology (ICT): General term for technologies in the fields of information exchange and communication.

[5] Manufacturing execution system (MES): Production management system operating near to processes, unlike ERP systems with a direct connection to the automation.

- User rights: The system has to be an intercompany system that shares data between different business partners in the value chain. For this reason it is important that the product tracking system provides a variety of user rights in order to configure the access of the traced data. This means that not every business partner in the value chain can retrieve or collect any kind of data.
- Supply chain event management integration: The product tracking system has to be part of the event management of TXTChain. During the template configuration created set points has to be evaluated at the data collection by the event manager.
- Workflow integration: The system uses flexible workflows to manage processes. So a user is easily guided through a sequence of activities. The product tracking system has to be integrated into this workflow management. So it has to be possible to create configurable activity reports or to manage a sequence of data collection.
- RFID integration: The product tracking system shall provide RFID integration. This means that RFID tags should be scanned directly into PTS. In fact, there are three different work practices possible:

    1. RFID-based automatic data collection: It is possible to store data direct on an RFID tag; for example quality data of an article. So the user should import data directly by scanning an RFID tag.
    2. RFID-based manual data collection: The user should scan an RFID tag as item identification and collect data manually.
    3. RFID-based data retrieval: The user should scan an RFID tag and the system shows all traced data for the scanned item.

5.5.5 The PTS Data Model

Before creating a common data model for data storage with unknown structure it is necessary to understand the structure of those data. After analysing different data sheets (Morgenstern 2008) which has to be traced, the basic structure as shown in Fig. 5.15 was designed.

Data belonging to the same pattern are called a template. Templates define the data that has to be traced. A defined template is the base for data storage. Stored data based on a template is called an instance of a template. Each template consists of several groups that are used to group together belonging data in form of tabs. Each of these groups or tabs has several parameters that represent the values to be traced. One parameter consists of an attribute and possibly some set points or a reference. References are data that has not to be collected. It is resolved by a calculation or by accessing existing data. Individual configurable set points could be created for every parameter of a template.

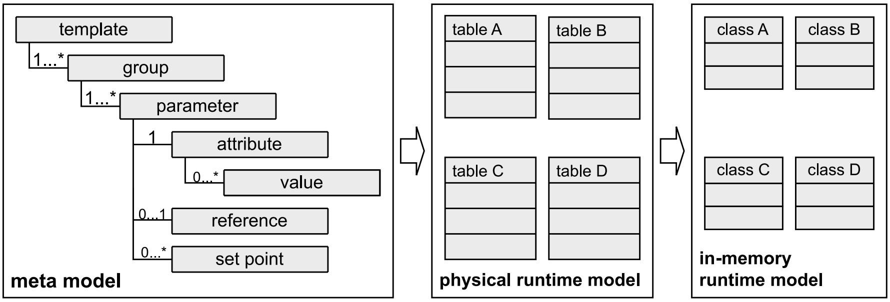

Fig. 5.15 Relation between meta model, physical runtime model and in-memory runtime model

Additionally, it is specified during the template definition to which entities of the master system an instance of a template should be assigned. Example entities are order, article, activity or delivery note. Also, the user rights for instances of a template are defined within this process.

Figure 5.16 shows the context between templates and instances. An example template has several assigned entity-groups (order, article, delivery note), and an instance of this template has assigned the entities (order 123, article shirt, delivery note 331).

As shown in Fig. 5.16 the product tracking system has a three-layer architecture. Based on the meta model, tables in the physical runtime model will be created. In fact for each group of a template a new table in the database is created. These tables contain instances of a template. The software system uses an in-memory runtime model to access the data. It has all necessary data to run the template or its instances. The benefit is that users only work with pre-selected data, which could also have another layout.

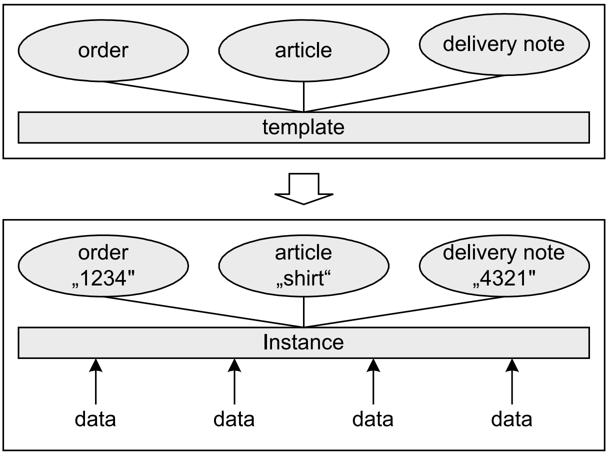

Fig. 5.16 Context of template and instance

The whole system uses a flexible data storage to memorise the templates and its instances. Within this data storage the well-used technique of data dictionaries[6] is used.

5.5.6 *Integration of the Product Tracking System*

The product tracking system was designed as new part of TXTChain, of which Fig. 5.17 shows the architecture. The grey-marked components tracking and tracing configurator and tracking and tracing engine are the new components for the product tracking system. The tracking and tracing configurator contains all functions to configure individual templates. The tracking and tracing engine with its parts data collection engine and data retrieval engine contains all functionality to collect, retrieve and analyse data.

All these components are integrated into the existing event management of TXTChain. The tracking and tracing configurator is able to configure set points for template parameters and can configure the behaviour at deviations from set points.

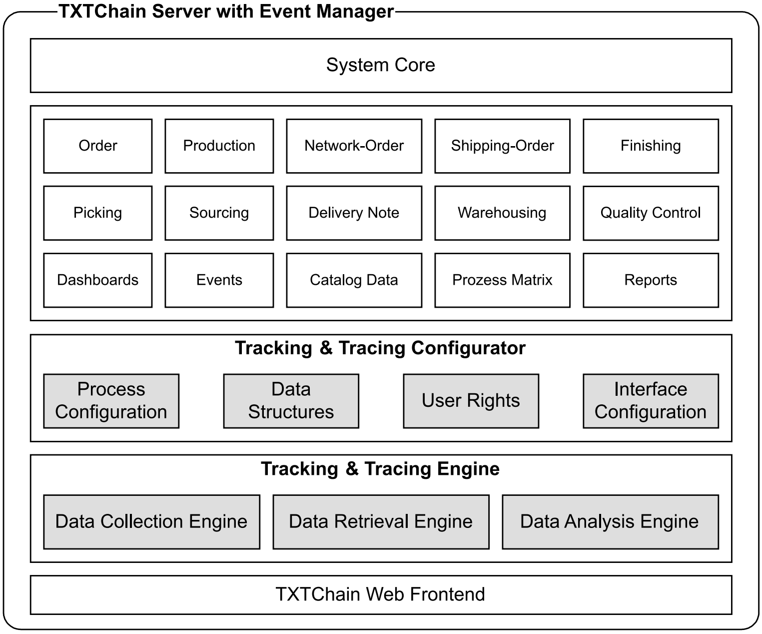

Fig. 5.17 Architecture of TXTChain including the product tracking system

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[6] Data dictionary: A "centralized repository of information about data such as meaning, relationships to other data, origin, usage, and format" (IBM Dictionary of Computing)

Tracking and Tracing Configurator

Templates of the product tracking system are completely configurable. The tracking and tracing configurator (see Fig. 5.18) is a powerful tool to configure entire templates. The user can configure various groups (tabs) with a variety of parameters using different types, such as:

- simple data types (strings, numerical data, timestamps);
- documents (MS-Office, PDF-Files, XML-Files, images and so on);
- lookup-tables[7];
- references to existing data and line by line calculations of values.

The user can also configure the access possibilities of the instances of a template for each business partner by a variety of pre-defined user rights. To observe deviations, it is also possible to configure set points and standard responses when a deviation occurs. This includes the definition of:

- set points for a parameter (depending on data type of parameter to observe);
  - single set points;
  - set point ranges (min, max);
  - parameter value of an group as set point;
- event receiver: Actor in the supply chain that shall be informed about the event;
- event message: Contains placeholders for the real value and maybe for the threshold value.

Each parameter could have a variety of set points. So the user is able to configure events for some different deviations.

Tracking and Tracing Engine

The data retrieval engine and data collection engine have to show, create, modify and delete instances of templates in the system (see Fig. 5.19). Therefore, there exists an user interface which is self adapting in dependence to the configured template of an instance. There is also the opportunity to search for special instances by using a flexible filter. To interact with third-party systems a XML system interface is available. This includes a system interface to ICT systems and a Web service. Especially the Web service allows an interaction of the PTS with an existing service oriented architecture, so that it can be used within a special business process.

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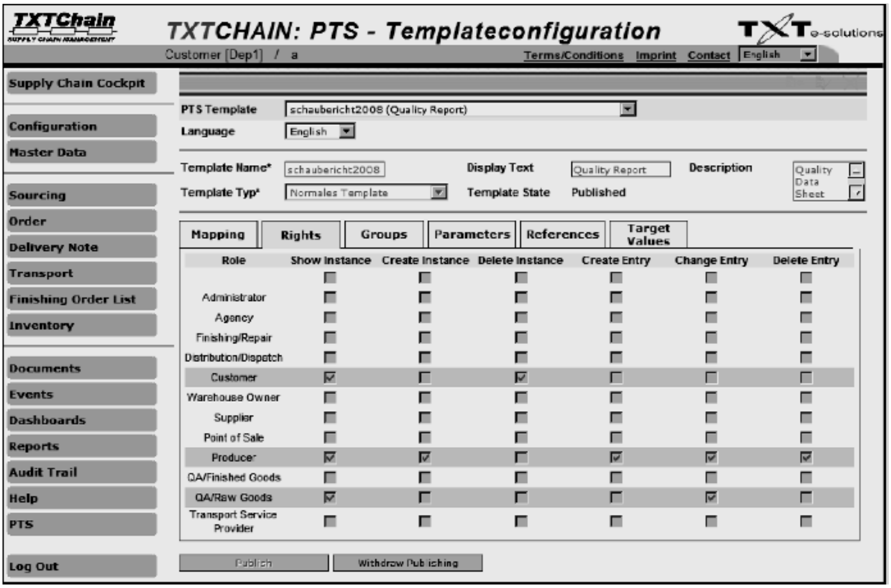
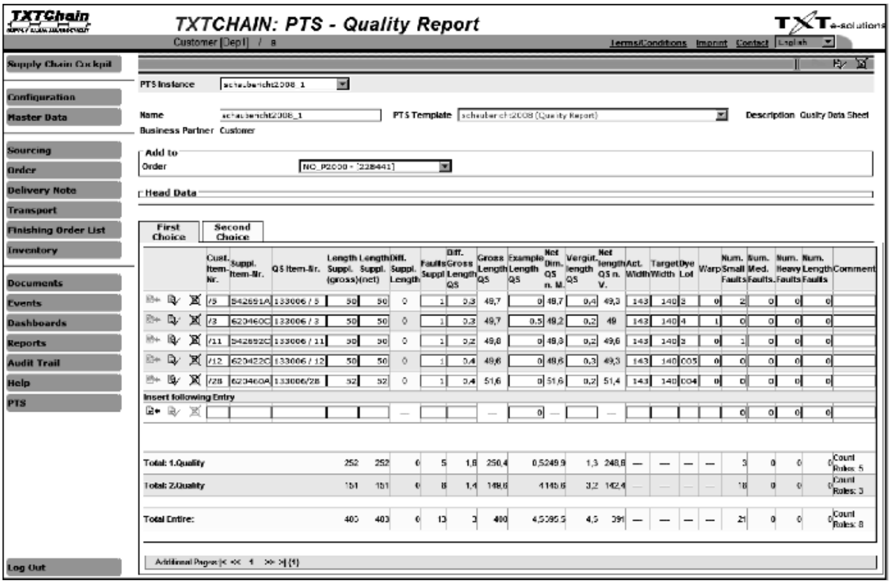
[7] Lookup tables (LUT): In this case a number of pre-defined values for example the values of a combo box or drop-down list.



PTS Template: schaubericht2008 (Quality Report)
Language: English
Template Name*: schaubericht2008
Display Text: Quality Report
Description: Quality Data Sheet
Template Typ*: Normales Template
Template State: Published

Role	Show Instance	Create Instance	Delete Instance	Create Entry	Change Entry	Delete Entry
	☐	☐	☐	☐	☐	☐
Administrator	☐	☐	☐	☐	☐	☐
Agency	☐	☐	☐	☐	☐	☐
Finishing/Repair	☐	☐	☐	☐	☐	☐
Distribution/Dispatch	☐	☐	☐	☐	☐	☐
Customer	☑	☐	☑	☐	☐	☐
Warehouse Owner	☐	☐	☐	☐	☐	☐
Supplier	☐	☐	☐	☐	☐	☐
Point of Sale	☐	☐	☐	☐	☐	☐
Producer	☑	☑	☐	☑	☑	☑
QA/Finished Goods	☐	☐	☐	☐	☐	☐
QA/Raw Goods	☑	☐	☐	☐	☑	☐
Transport Service Provider	☐	☐	☐	☐	☐	☐

Fig. 5.18 Screenshot of the tracking and tracking configurator



PTS Instance: schaubericht2008_1
Name: schaubericht2008_1
PTS Template: schaubericht2008 (Quality Report)
Description: Quality Data Sheet
Business Partner: Customer
Add to
Order: NO_P2000 - [228441]

	Cust. Item-Nr.	Suppl. Item-Nr.	QS Item-Nr.	Length Suppl. (gross)	Length Suppl. (net)	Diff. Suppl. Length	Faults Suppl	Diff. Gross Length QS	Gross Length QS	Example Length QS	Net Dim. QS n. M.	Vergut.-length QS	Net length QS n. V.	Act. Width	Target Width	Dye Lot	Warp	Num. Small Faults	Num. Med. Faults.	Num. Heavy Faults	Num. Length Faults	Comment
	/5	542691A	133006 / 5	50	50	0	1	0,3	49,7	0	49,7	0,4	49,3	143	140	2	0	2	0	0	0	
	/3	620460C	133006 / 3	50	50	0	1	0,3	49,7	0.5	49,2	0,2	49	143	140	4	1	0	0	0	0	
	/11	542692C	133006 / 11	50	50	0	1	0,2	49,8	0	49,8	0,2	49,6	143	140	2	0	1	0	0	0	
	/12	620422C	133006 / 12	50	50	0	1	0,4	49,6	0	49,6	0,3	49,3	143	140	C05	0	0	0	0	0	
	/28	620460A	133006/28	52	52	0	1	0,4	51,6	0	51,6	0,2	51,4	143	140	C04	0	0	0	0	0	
Insert following Entry																						
						—			—	0	—		—					0	0	0	0	
Total: 1.Quality				252	252	0	5	1,8	250,4	0,5	249.9	1,3	248,8	—	—	—	—	3	0	0	0	Count Roles: 5
Total: 2.Quality				151	151	0	8	1,4	148,6	4	145.6	3,2	142,4	—	—	—	—	18	0	0	0	Count Roles: 3
Total Entire:				403	403	0	13	3	400	4,5	395.5	4,5	391	—	—	—	—	21	0	0	0	Count Roles: 8

Fig. 5.19 Screenshot of the tracking and tracing engine

Integration into the TXTChain Web Front-end

The product tracking system is integrated with a variety of modules of TXTChain, for example order module or delivery note module. So it can be used to trace data. Furthermore, is has been integrated with the workflow management component. So the user is able to configure activity reports in a workflow by its own.

RFID Integration

The system provides the opportunity to scan an RFID tag, which is modelled as an entity. The product tracking system is able to map instances to an RFID tag, and the user can scan an RFID tag thus enabling to collect data or to show all traced data. For the future it is planned that import data can be written directly to the RFID tag.

5.5.7 Example Scenario

The following example scenario shows a typical use case for the product tracking system. Given that a customer has ordered some silk fabrics to produce a ladies' blouse. He orders some silk bales and delivers them to a producer who cuts and sews the fabric parts. Before the user can design the templates for tracing data, it is necessary to analyse the value chain to specify the data to be traced. Figure 5.20 shows an example use case and visualises the parts of the value chain.

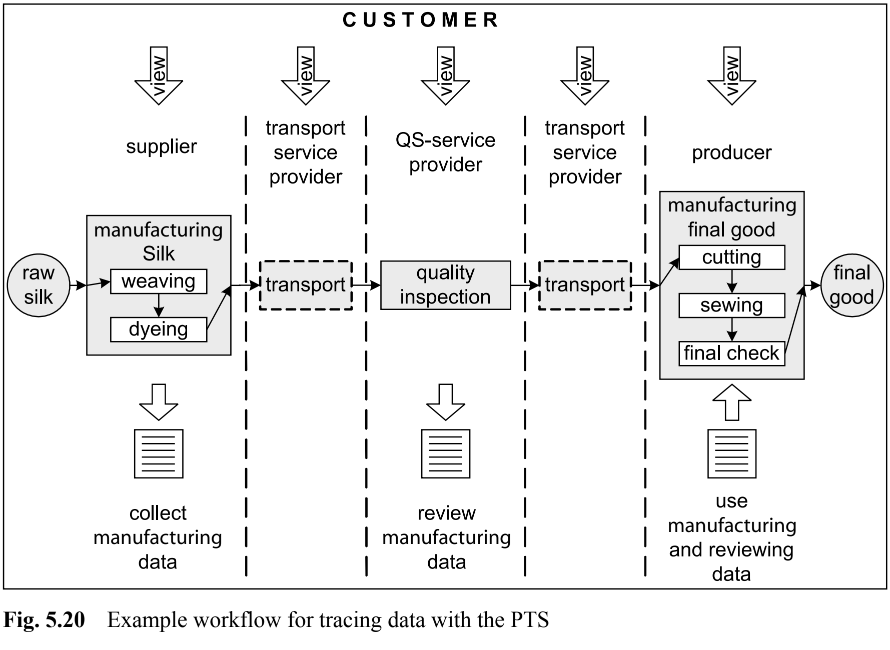


Fig. 5.20 Example workflow for tracing data with the PTS

With the product tracking system included into TXTChain the customer is able to define data templates for each stage of the value chain. The business partner has to fill in the needed data in its stage and the customer or other business partner can use this data for his purposes. So, the customer is able to trace data though the whole value chain.

5.5.8 Outlook

During the LEAPFROG project a prototype of the product tracking system was designed and developed as new module of TXTChain. Currently a part of the product tracing system is in use at a well-known fashion discount retailer. Furthermore, there are some demonstration cases and industrial prototypes with different business partners of the LEAPFROG project, with the objective to get feedback from the industry. Following are some statements of test partners:

- Oui Group, Munich, Germany (one of the most successful companies in the international fashion industry with two main labels Set and Oui, www.oui.com): "Because of the fact that data is electronically available we will be able to process the data faster and better."
- Zuleeg, Helmbrechts, Germany (a producer of high-quality woven fabrics, http://www.zuleeg.de): "The PTS is generally a good idea. Our customers can retrieve the data more quickly. The benefit for our company is that we could offer our customers, who already use this system, a better service. Because of this, we expect a greater competitive advantage."

This feedback is very important for the further development of the product tracking system in order to improve the concept and the system. Some of the suggestions of the test partners have been already incorporated into an extension of the PTS.

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Chapter 6
Conclusions: Results Achieved, Lessons Learned, Follow-Up Research Work and the Industry's View on the Way Ahead

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6.1 Overall Appraisal of the Results Achieved

The preceding chapters intended to provide details about all significant research components of the LEAPFROG project. The authors also tried to demonstrate that all research work had been undertaken on the basis of a sound analysis of pre-existing scientific-technological state-of-the-art, industrial capacities, business models, market needs and their expected future trends as well as human factors such as available skills and qualifications or management procedures and cultures. Finally it should have emerged that despite their great scientific and technological diversity all four major research modules of the project fit into a holistic re-engineering framework reflecting the real complexities and interdependencies of the different manufacturing stages and business processes along the textile-clothing value chain, in the sense of a true integrated industrial innovation concept.

Several research results have, during the course of the project, reached a level of technological maturity that extensive testing and demonstration work in the real business environment could have been carried out and a rapid commercial exploitation and industrial implementation can be expected at the end of the project. This applies specifically to developments in the research modules relating to virtual clothing prototyping (see sections of Chap. 4) and the extended smart garment organisation (see sections of Chap. 5). The industrial opinions provided below are mainly related to achievements detailed in these two chapters.

In other areas, major basic technical bottlenecks were successfully overcome, but more component development, overall system engineering and extensive industrial testing work will be required before commercial exploitation and industrial implementation at a significant scale can occur. This applies specifically to the innovative fabric handling, joining and garment assembly processes described in Chap. 2 and Sect. 3.2. Even more research and development work will be needed to transform the targeted fabric shaping and stiffening concepts discussed in Sects. 3.1 and 3.3 into the sufficiently robust and economically viable processes necessary for industrial exploitation.

6.2 Lessons Learned from the LEAPFROG Project

The LEAPFROG project could demonstrate that a strategically built and coordinated international consortium of scientific and industrial partners bringing together multi-disciplinary but complementary expertise and capabilities can effectively reach technological advances that are difficult to realise in individual ad-hoc efforts.

LEAPFROG benefited in particular from the following elements:

1. It brought scientists and technology developers in fields such as advanced materials, robotics, virtual reality or management research to focus on developments for application in the textile and clothing industry which is rarely the target of developments in these scientific domains. In addition, the constant exchange of scientists and industrial practitioners over an extended period of time enabled a rapid learning curve among the developers about the real problems and requirements in industry and among the users about the capabilities and potential benefits of applying new concepts and technologies in their businesses.
2. The pooling of technological, organisational, human and financial resources and the substantial project cofunding by the public, i.e. the EU Research Framework Programme, made it possible to carry out research and development work at a level of technological risk and a time horizon that would have been impossible for an individual company or a pure private sector consortium. Proof of this is that an initiative of similar subject and scale has not been undertaken since the Japanese TRASS project in the 1980s.
3. The combination of research, development, demonstration and training activities in a single project covered a broad area on the continuum spanning from fundamental science to commercial use and thereby helped to avoid breaks in this continuum that often occur when narrower short-term projects fail to connect to the next step, generally due to lack of follow-up funding.
4. Different positive spill-over effects were registered throughout the project. These included the transfer of concepts or technologies from one research module to another or the transition of partners especially industrial users from one project development to another for which they only discovered their interest or potential benefit during the course of the project.
5. The fact that a considerable number of previously non-cooperating organisations from different European countries, adjacent scientific disciplines or different parts of the industrial value chain started to collaborate under the project umbrella will be a great facilitator to follow-up research and development or industrial exploitation.

Not all of the lessons from the LEAPFROG project were positive. Some of the more negative points include:

1. The complexity of overall coordination and management of such a large-scale international consortium of individual organisations that sometimes unnecessarily slowed down information flow and decision-making processes in the project.

2. The rigidities built into a typical European research funding contract that make project partner changes, research programme modifications, task and budget transfers as well as reporting and payment processes rather lengthy affairs. Actually, some delays occurred while partners were waiting for the official acknowledgment of a contractual change or the next payment.
3. Finally, some of the benefits of the rather long-term nature of the LEAPFROG project running for more than 4 years were mitigated by changes in personnel or organisational priorities at the individual partners during the course of the project. In total, 2 partners left the consortium while several others scaled-back their activities significantly while remaining in the consortium, on the other hand 3 new partners joined the project and several other previously unrelated organisations became involved in project activities by becoming a member of the coordinating body AADLT, the Association for Advancement and Dissemination of LEAPFROG Technology.

6.3 Follow-Up Research Work

While a number of LEAPFROG developments will in relatively short time become part of commercial products and services, results across all research modules also provide ample scope and interesting potential for follow-up research and development work. While it is virtually impossible to list all started, planned, intended or potentially feasible follow-on projects of the 35 individual project partner organisations, a number of more significant collaborative initiatives again under the umbrella of the EU Research Framework Programme can be referenced or indicated.

Two new European projects were launched in late 2008, in the fields of virtual garment prototyping and smart networking to enable more efficient and consumer-oriented mass customisation of clothing and fashion.

The SERVIVE project (SERVice Oriented Intelligent Value Adding nEtwork for Clothing-SMEs embarking in Mass-Customisation), EU Grant CP-TP 214455, 2008, under the leadership of LEAPFROG partner Athens Technology Center, aims at:

- the enlargement of the assortment of customisable clothing items currently on offer (moving the focus to women's wear, knitwear and sportswear);
- the enhancement of all customer-involvement aspects (encouraging the active participation of end consumers in the configuration of the customised items);
- the development of a virtual customer advisor (VCA), an intelligent system, which depending on the profile of the customer will recommend the optimum product configuration; and
- the development and testing of a new production model based on decentralised high-tech manufacturing cells (micro-factories).

Further LEAPFROG partners also active in this project include IFTH (Institut Français du Textile et de l'Habillement), Miralab (University of Geneva), and the Hohenstein Institutes (Bekleidungsphysiologisches Institut Hohenstein e.V.).

In the same overall domain, the Open Garments project (www.open-garments.eu), led by LEAPFROG partners DITF-MR and Bivolino.com focuses on empowering the consumer as designer, producer and retailer for individual garments. The approach is:

- to harness the capabilities, the knowledge, the creativity, and the willingness of consumers by means of web-based virtual communities of individuals;
- to adopt and integrate (mainly) existing digital technologies for design and production of individual garments in a framework of open innovation (OI) and (a new concept of) open manufacturing (OM); and
- to combine all these elements in a new organisational concept for SMEs with an appropriate business model and tools for the manufacturing service provider (MSP), which coordinates, supports and partly manages the open innovation consumer community and the open manufacturing network.

It would mean a radical change of the system, giving the consumer direct influence in the way his or her garment is designed and configured. To make this possible the Open Garments project is developing a new design, production and sales process based on the internet. The overall objective of the project is to establish the perfect business model for this innovation: *the manufacturing service provider business model.*

LEAPFROG partners TXT e-solutions and ColorTextil also participate in this new project.

Finally, some of the LEAPFROG partners involved in research work dealing with automation of clothing production and related processes may pursue together funding opportunities which are expected to become available as part of the 7th EU Framework Programme in 2009 or 2010.

6.4 Industrial Appraisal of the Research Results and Reflections on Possible Future Developments

As described in details in several herein presented sections as well as earlier in this chapter, industrial user companies were extensively involved in testing, demonstration and training activities related to several LEAPFROG research results. The following statements exemplify the commitment and belief of some of the involved industrial partners in the commercial potential of various project results and will also hint at some further needs and expectations for innovative concepts and technologies to drive productivity and added value in the European textile-clothing chain.

HUGO BOSS AG, Germany is one of the global market leaders in superior fashion, with worldwide distributed new product development, material sourcing and production. Following its mission “Think global – act local”, and “Make processes transparent”, the company expected through LEAPFROG to significantly improve partnerships for creativity, flexibility, and quality.

Matthias Behr, responsible for the product division 'clothing man' states "The question must not simply be, whether the product meets the specification or not. We need a quality improvement process along the complete supply chain in the whole lifecycle!"

The approach was to first solve problems with the textile supplier partners, focussing on fabric quality. The new quality partnership was developed, implemented and trained, and is now successfully applied. In 2008 more than 10 suppliers were part of this quality assurance initiative and signed a quality-assurance agreement. Lead-time reductions and cost savings were the positive result.

Ermenegildo Zegna Group, a world leader in luxury men's clothing, stated: "We do not have the lowest labour costs like Vietnam or China, but we still have a first class methodology, technology and passion for our work, that can still ensure European Companies a very solid perspective for good business in the next decades." In particular, the interesting and effective way of coopetition – competition and cooperation – experienced with Hugo Boss, with whom we shared quality criteria, fabric purchase methodologies and the use of standards for electronic communication in such a partnership led to promising results. "We realised that we are not alone in our belief in the perfect feasibility of development and production of high quality clothing and fashion products in Europe and we will continue in our commitment in this direction planning to work with some LEAPFROG partners also in the future."

Wilhelm Zuleeg GmbH, a German SME producing a wide variety of piece dyed or colour woven fabric for the high-quality ladies and menswear market, started with high expectations, and finished with benefits that even exceeded those expectations. Their work focused on a broad range of LEAPFROG themes, which involved many employees of the company, and that was guided by the Management Centre of the German Institutes for Textile and Fibre Research Denkendorf (DITF-MR).

Klaus Zuleeg, one of the owner-managers of the company, stated: "We developed and implemented in a very close and constructive cooperation with suppliers and with our customer Hugo Boss the New Quality Partnership, which is unique in the fashion industry. The processes for quality assurance and testing are harmonised, and we became the first supplier of Hugo Boss, which qualified for Direct Delivery. The process FMEA led to a significant improvement of the process capability, which led to a sustainable reduction of costs and time, and improvement of competitiveness, in particular in this partnership of textile and clothing industries. This is an important factor for maintaining our European manufacturing location.

LEAPFROG enabled us to research and test new ways of working and collaborating much more closely and deeply with various value chain partners. This would not have been possible for us without participation in the LEAPFROG research project, as most commercially offered technological and organisational innovations are typically cost-driven, and often realise no durable strategic benefit. The results of LEAPFROG had a truly long-term transformational impact on our company which will continue to positively reverberate on all our supply chain relationships."

Fratelli Piacenza S.p.A., a leading producer of noble fibre fabrics in the top segment for luxury fashion, expected to significantly improve its collaboration with value-chain partners. They achieved this goal by developing and implementing a knowledge-exchange infrastructure leading to a global supply chain vision. Based on the Moda-ML standard, these results of LEAPFROG are being put into industrial practice, thus demonstrating the potential benefit in the business relationship with other partners, in particular with the Ermenegildo Zegna Group, in the true spirit of collaborative research.

This also applies to the development and application of robust RFID tags in the production processes, and to the integration of the fabric CAD system with the Collaborative Virtual Prototyping platform, which is a major step towards a complete virtual prototyping process in the industry. Piacenza: "Beside these significant technological and economical benefits, we were able to collaborate with first class European research and industrial partners and to build long lasting international relationships."

For Hervé François, Managing Partner of Color-Textil Veredelung and Color-Web GmbH, a German-based fabric design and printing solutions provider, the LEAPFROG project was exceptional both in its vision and in its scope of tasks that were undertaken. "For a textile printing mill with both traditional and digital facilities, our participation in the colour-management task confirmed us in our commitment to contribute to a network of partners ranging from the textile and clothing industry to application developers, research institutions and designers. In a much smaller way, our group of companies is already an active promoter of young design talents, by founding and maintaining the exchange forum *rooms for free e.V.* which links textile companies and European design academies. We think that networking capabilities across all textile production steps within Europe is an essential element to stabilise the long-term outlook for our industry.

Colour management plays now an important role in aligning our digital printing facilities at Color-Web GmbH with the demand of our customers from the clothing industry. It enabled us to build efficient structures for the cooperation in product development. All in all, LEAPFROG accompanies and enables a change of management from traditional manufacturing to digitally controlled processes in the European textile and clothing industry in the near future."

Michel Byvoet, owner and creator of Belgian-based Bivolino.com providing mass customised garments over the Internet, found many of the technology concepts and services (such as 2D-CAD with 3D visualisation, QBM, fabric draping, Bivotrack) developed within LEAPFROG for clothing companies useful as they will enhance 'customer-centric' business opportunities. "The developed tools leading to a 'create-your-own' perspective through 3D e-configurators will guarantee a new technology base enhancing the mass customisation opportunity and effective consumer involvement. Bringing fashion & technology together in a prosumers' view is the challenge for the next decade, creating new micro production facilities for the textile and clothing industry in Europe."

For Mr. Olivier Ven, Head of the Apparel Quality Department of La Redoute, a leading international mail order retailer headquartered in France, the LEAPFROG project started with the following four clear stakes for which effective solutions should be found.

- Stake 1/Reduce 'time to market'
  Being able to avoid useless intermediary prototypes can save us between 3 and 6 weeks during the design and prototyping stages. Each saved week enable our designers to finalise the collections closer to our final customer and their seasonal expectations.
- Stake 2/Facilitate our creativity
  Added value of creative staff is often restricted by budgetary and schedule issues during sampling.
  Having an efficient tool of 3D visualisation in addition to a strong in house patterning office is going to let us create as much as we want. The stake is to 'create and visualise in real time'. It's going to set up a new job in between designers and pattern makers.
- Stake 3/Adjust our fitting to our worldwide customers
  Sales are international. Customers are located everywhere.
  The LEAPFROG collaborative virtual prototyping platform, along with the 3D CAD will enable us to try our development samples on virtual international models (mannequins) in addition to our usual French models, in order to let us choose the best average solution.
- Stake 4/Improve our price quoting
  The more we facilitate our creativity, the more we must ensure that our creations comply with our economical targets. The stake is not only to 'create and assess in real time', but also 'to create, visualise and define price in real time'.

Our evaluation of the results today

In terms of efficiency (Concerns stakes 1/2/3): Software and web services developed within the LEAPFROG project have proved their efficiency in terms of enabling 3D visualisation of a creation with a very good level of accuracy.

Through this, we are now quite sure that this will be soon necessary as a kind of 'missing link' between the creative and the technical staff in our organisation.

We still need to implement detailed tests concerning the effectiveness of these tools and services to be of real help regarding fitting issues (Stake Nr 1). Besides, in our practice, there is still a cultural gap between visualising a model on a PC screen and reviewing it physically through a trying on session.

The fact that a virtual model can be configured according to various anthropometric profiles is crucial for assessing the 'universality' of our collections, which is now 100% strategic.

Our needs for the immediate future

Price quoting (Stake Nr 4) is something which has to be experienced now 'for real' soon. Even if creation is essentially free at the very beginning of a new collection development process, then very early on, budget issues influence strongly our decisions.

The CVP on-line link to the cost-estimation module enables to interactively develop on screen and visualise new garment models while we can immediately check also how much the final product might cost. This would be a strategic implementation for this project, which cannot be disconnected from business issues.

As a private company, our ‘life rhythm’ is naturally different from most R&D partners. We do need our partners to propose now a real ‘product’ that can be purchased, including not only a high level of efficiency, which has been duly demonstrated, but also a fair level of comfort and service.

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