Technical University of Crete
School of Production Engineering & Management

The effective integration of 3D virtual prototype in the product development process of the textile/clothing industry

Doctoral Dissertation
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Αποτελεσματική ενσωμάτωση του 3D εικονικού πρωτότυπου στην διαδικασία ανάπτυξης προϊόντων της βιομηχανίας της Κλωστοϋφαντουργίας & Ένδυσης

Διδακτορική Διατριβή

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To my son

Summary

The Textile, Clothing and Fashion Sector (TCF), is one of the first industries to be importantly affected by the globalisation of production and services. The clothing industry is driven towards a permanently accelerating fashion, offering its products faster, cheaper, and in bigger abundance than ever. This demand has resulted in the search of new techniques that will add value in the product development process.

The present research's scope is the study and acceptance of digital prototype as mean of communication and abbreviation of product development time without problems, decreasing the technological gap and the time of production, increasing at the same time the creativity and the direct visualisation of clothes and its application.

Digital prototype has become acceptable in the electromechanical products applications and several studies have revealed the most optimal exploitation of new technologies' possibilities and the problems raised from its integration in the development process. In the TCF sector, the research is directed towards the development of plan study solutions with the aim of an emerged satisfactory digital prototype model that could integrate into the existing designing solutions.

The objective of this research study is to give prominence to the integration demands and requirements as well as the effective use of digital three-dimensional model in the fashion process via extensive research of academics, technology vendors, users, designers and experts in clothing and fashion products.

Περίληψη

Ο κλάδος Κλωστοϋφαντουργίας και Ένδυσης (ΚΥ&Ε) είναι από τους πρώτους βιομηχανικούς τομείς που επηρεάστηκαν σημαντικά από την παγκοσμιοποίηση της παραγωγής και των υπηρεσιών. Η βιομηχανία της μόδας οδηγείται προς μια διαρκώς επιταχυνόμενη μόδα που προσφέρει τα προϊόντα της γρηγορότερα, φθηνότερα και σε μεγαλύτερη αφθονία από ποτέ. Η απαίτηση αυτή έχει ως αποτέλεσμα την αναζήτηση νέων τεχνικών που θα προσφέρουν στην διαδικασία ανάπτυξης προϊόντων.

Η παρούσα έρευνα έχει ως αντικείμενο την μελέτη και αποδοχή του ψηφιακού πρωτοτύπου ως μέσο επικοινωνίας και σύντμησης του χρόνου ανάπτυξης του προϊόντος χωρίς προβλήματα, μειώνοντας το τεχνολογικό χάσμα και τον χρόνο παραγωγής, αυξάνοντας παράλληλα τη δημιουργικότητα και την άμεση οπτικοποίηση του ρούχου και της εφαρμογής του.

Το ψηφιακό πρωτότυπο έχει γίνει αποδεκτό στις εφαρμογές ηλεκτρομηχανολογικών προϊόντων και πολλές μελέτες έχουν αναδείξει την βέλτιστη εκμετάλλευση των δυνατοτήτων των νέων τεχνολογιών και τα προβλήματα από την ενοποίησή του στην όλη διαδικασία ανάπτυξης. Στον τομέα της ΚΥ&Ε η έρευνα κατευθύνεται προς την ανάπτυξη λύσεων σχεδιομελέτης ώστε να προκύψει ένα ικανοποιητικό μοντέλο ψηφιακού πρωτοτύπου που θα μπορούσε να ενοποιηθεί στις υπάρχουσες σχεδιαστικές λύσεις.

Σκοπός της έρευνας είναι να αναδείξει τις απαιτήσεις ενοποίησης και αποτελεσματικής χρήσης του ψηφιακού τρισδιάστατου μοντέλου στη διαδικασία της μόδας μέσω εκτεταμένης έρευνας ακαδημαϊκών, παρόχων λογισμικού, χρηστών, σχεδιαστών και ειδικών προϊόντων ένδυσης.

Publications

For the fulfilment of the present presentation, 7 papers were published in scientific journals, book chapters and international conferences as follow:

Journals:

1. Papachristou, E., Bilalis, N., (2015). How to integrate recent development in technology with digital prototype textile and apparel applications. *Marmara. Journal. Pure Applied. Sciences.* 1, 32–39

2. Papachristou, E., Bilalis, N. (2016), Can 3D prototype conquer the apparel industry? *Journal of Fashion Technology & Textile Engineering*, 4:2

3. **Book Chapters:**
   Papahristou, E., Bilalis, N., (2016). A new sustainable product development model in apparel based on 3D technologies for virtual proper fit. In book: *Sustainable Design and Manufacturing 2016*, Edition: Smart Innovation, Systems and Technologies 52, Springer International Publishing, Editors: Setchi,R., Howlett, R.J., Liu, Y., Theobald, P., pp. 85–95

4. **International conferences:**
   Papahristou, E., & Bilalis, N., (2014). How to integrate recent development in technology with digital prototype textile and apparel applications, *6th International Istanbul Textile Conference Future Technical Textiles* (FTT 2014) Istanbul, Turkey, 15–17 October 2014

5. Papachristou, E., Bilalis, N., (2015). Wearables Towards A new Product Development Model, Poster Presentation at *IDTechEx Printed Electronics Conference & Tradeshow*, Berlin, 28–29 April 2015

6. Papachristou, E., Bilalis, N.(2015), Can 3D prototype conquer the apparel industry? In: *15th AUTEX World Textile Conference* Bucharest, Romania, 10–12 June 2015

7. Papahristou, E., Bilalis, N., (2016). A new sustainable product development model in apparel based on 3D technologies for virtual proper fit, *International Conference on Sustainable Design and Manufacturing*, Chania, Crete, Greece 4–6 April 2016

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I would also like to express my very great appreciation to Prof. Aristomenis Antonaidis and Prof. Vassilios Moustakis, members of my advisory committee, for their valuable advice during my Ph.D studies.

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I wish to express a sincere thank you to those who so graciously agreed to participate in my study. In the course of gathering this material, interviewing the participants, and collecting the data, I had invaluable assistance from the men and women who agreed to share with me their experience with new technology in the product development process of the fashion industry. Without them, the completion of this study would not have been possible. I thoroughly enjoyed each and every one of them and learned so much from their "experience wisdom" that I can share with all of you.

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Finally, I would like to dedicate this thesis to my son, Stylianos. He has been my life beacon, showing me unconditional love and support especially through out these years of research. His confidence in me and in this research successful completion was instrumental. I am very blessed to have him; I wish him the world and beyond.

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Introduction

1 Introduction

The textile and clothing industry is a mature industry trying to revive its' fortune through the adoption of novel technologies, moving away from traditional roots. Digital Prototyping, driven by three dimensional (3D) technology, is considered to be an essential tool in the modern design process. Its integration can speed up the design process, offer products made in a better, cheaper and more efficient way, influence competition between companies. Virtual Prototyping, while well established in many other industrial sectors like automotive, aerospace, architecture and industrial design, has only just started to open up a whole range of new opportunities for apparel designers. Typical applications affected by Digital Prototyping are digital textile and fashion design, pattern generation to custom-design clothing, fitting evaluation, style editing, and virtual try-on. The effective integration of true to life 3D visualisation and virtualisation solutions results in the digital clothing product development process, creating a future scenario of operation with fashion designers and clothing product developers totally familiarised with this new technology; a scenario these days more down to earth and less science-fiction.

1.1 Technology in the Textile and Clothing Industry

The global textile, clothing and fashion (TCF) industries are one of the most competitive and skilled-labour dependent industries with growing complexities and market dynamics related to globalisation and competition. Moreover, differentiation has become a key aspect in developing competitive advantage for these TCF firms owing to greater market dynamics, rapid fluctuations in postmodern consumer behaviour, shortening of fashion product life-cycle, product proliferation, to mention a few (Pal & Torstansson, 2007).

The skilled-labour dependent nature of apparel design did not encourage to a large extent automation and software programs application (Fontana et al, 2005). Since the 1990s software for use in the TCF industry has become increasingly sophisticated. Computer-aided design (CAD) was initially developed as an interactive computer design system for the textile industry, then introduced into apparel for pattern making and grading, and has been further developed for fashion and clothing design. Computer-aided manufacturing (CAM) was initially developed as a way of ensuring that the transition from 2D design process to 3D manufacture was more seamless, and also enable companies to benefit from quick responses (Burke & Sinclair, 2015). Just as CAD enables design businesses to participate within a global field, so does the ability to integrate CAM, which enables companies to test physical prototypes (Jones-Jenkyn, et al, 2011) and streamline production processes.

More recently, (Meng et al, 2012), mentioned that the traditional apparel product development process is a typical iterative 'optimisation' process that involves trial-and-error. In order to confirm the design and achieve a satisfactory fit, a number of repeated cycles of sample preparation, trial fitting and pattern alteration must be conducted. The process itself is time-consuming, costly, and dependent on the designer's skills and experience. At the same time, design, development and sourcing teams have been impacted and are often under pressure to do more with less. Making numerous sketches, drafts and samples takes time. The diversity of clothing styles and designs is hardly found in any other industry. Fashion and apparel companies have been forced to look inward and reevaluate how they bring products to market. Updating technologies is a common place to start but changing the process across the organization results to real gains. It is claimed by technology providers that by using correct technologies, major players are reducing their development time by 20 to 50% (Lanninger, 2014).

However, a scenario of an apparel industry with fashion designers who do not use pencil and paper and do not pass these designs to the pattern maker to digitally sew and evaluate them in a 3D model is still far too optimistic. A future scenario of a fashion designer comfortable enough with 3D technology to create from the beginning that initial fashion drawing in a three-dimensional space making quick decisions, trying out different fabrics, colors and contrasts, communicating his/her ideas with the pattern maker and the entire development team in true to life 3D and within hours instead of days or weeks, sounds science-fiction.

3D technology has been available for some time. Historically, it has always been difficult to use, with complicated interfaces and limited functionalities. It is argued that 3D modelling software allows designers to build and visualise 3D models of clothing prior to being constructed overseas, thus saving a lot of time, money and effort. By contrast, it is posited that many processes still do not live up to their full potential. As it was previously mentioned, the fashion business and the fashion industry has been slow on the uptake, because it wasn't as refined as it is today. We are at a point where it's not only easier to use but it's also much more realistic. 3D technology providers have been launching marketing campaigns, international events (involving the industry and the academic institutions), dedicated to the transition the fashion industry needs to go through the concept of three-dimensional working processes not only in product development side but in marketing and e-commerce as well.

At the global retail side, the virtual human modelling concept has become very important, and companies are conducting research on systems to quickly develop 3D avatars for virtual try-on. The ability to create colour body scans, and the capability of 4D body scanning, will have useful applications for apparel Product Development in the future.

With tech-companies becoming more transparent, tools from one company will be able to communicate with the tools from another tech-company, providing better technological collaboration for apparel Product Development (Senanayake, 2015). While evolving technologies in 3D design environment are trying to convince clothing brands & manufacturers to invest in both chain management and in the infrastructure and architecture itself going through the journey of 3D scepticism to 3D evangelism, attention is also gathered in the retail space with virtual and augmented reality technologies. Smart virtual mirrors connected with RFID clothing tags, beacons and smart chip solutions allow customers to virtually try on products gaining personalised offers and at the same time track inventory from the warehouse to delivery to the store. The growing market of fashion wearables and Internet of Things provide the clothing businesses with crucial information and data about their consumer or wearer in an almost effortless way (Harrop, 2016).

1.2 The Problem

Design, Development and Production have largely relied on the same, often manual, methods despite all the technological advances happening in the world outside of fashion and apparel. Ten years ago, academic research (by contrast to the existing 3D virtual software solutions) posited about clothing companies complaints on the lack of effective garment-oriented CAD packages to design directly in 3D and provide the modellist with tools for shape modelling and cloth behaviour simulation (Fontana et al, 2005). Nowadays, with the growth of demand from better educated consumers, mass customization, e-commerce, advances in virtual reality applications, the virtual garment development is strongly desired in order to optimise apparel industry's design and development processes.

However, the use of 3D prototyping solutions in the apparel industry is still lagging behind in comparison to other industries (such as, e.g. the automotive) although many vendor companies state that 3D prototyping once considered time-consuming and cost prohibitive, today has the potential to develop innovative products with the optimal balance of style, quality and cost (Dassault, 2015). The clothing industry once data-driven and silo-mentality oriented, is moving towards a model-driven approach with three-dimensional offering the best representation of a product's identity.

In this thesis, the effective integration of Digital Prototype in the Product development process will be examined. We investigated the level of the technology implementation in the early adopters, the vision of the big corporations, entrepreneurs and professional users for the global clothing and fashion industry as well as the challenges, opportunities and barriers that need to be overcome in order for digital prototype to accelerate business processes on an integrated basis. During the process of identifying everyone affected by a change initiative, we grouped the areas that will be impacted by the new involved technology implementation like 3D prototyping & visualisation or PLM and according to their roles and relationships with the industry we divided them in 4 groups:

1. Technology providers-vendors

2. Managers-executives-professional users

3. Entrepreneurs-independent user

4. Academics

This research project has been contacted using a combination of primary and secondary sources. First hand interviews with the previously mentioned categories were used, alongside extensive secondary research conducted at workplaces using the modern technology, trade conferences & exhibitions, together with comprehensive review of current publications and research results. Concretely, the main research questions of this thesis are the following:

Question 1 — What are the main differences between 2D and 3D processes?

Question 2 — The new and emerging 3D virtualized product development process promises reduction on physical samples, shortened lead times, efficient production, earlier and quicker decisions, competitiveness, improved communication, even increase in e-commerce sales. However, this new technology is rarely seen fully integrated even in giant brands. What are the common problems that the small-medium brands face and what are the problems when it comes to large clothing brands?

Question 3 — Most manufacturers begin the design phase in the traditional manner with 2D sketches and concept production. This creative output then passes through the classical product development cycle, from preparation of the cut pattern, to sewing the prototypes, and after innumerable iterations finally reaches the production stage. With the use of 3D virtual technology, how the above traditional method has been altered?

Question 4 — What are the main challenges the industry faces in the adaptation of new technologies, if the traditional product development process no longer works?

Question 5 — Who is going to be part of the 3D development of clothes and its role in the future?

Question 6 — In education and especially in the learning process of design, is the mentality evolving taking into consideration new concepts and environments like the one of 3D? Is this new process supported by academic staff with knowledge and mindset in designing in 3D virtual prototype?

Question 7 Does 3D fit technology fall right in line with companies' increasing desire for green practices? Fewer prototypes mean less energy spent on shipping and transportation, fewer chemicals used in preparing fabrics and reduced waste. Do fashion companies have the same philosophy and show the same sensitivity towards those matters when investing on 3D virtual prototyping?

Question 8 The IoT provides fashion businesses with vast amounts of data, but they still aren't using it effectively (i.e. not integrated process of new product development with customer body size data). How will we see a greater understanding of the value of this data, how to use it and make better decisions and how to pinpoint what data from sensors and connected technology is best utilised?

Question 9 Will 3D prototyping and visualisation tools will become mainstream tools in the fashion industry? How 3D can alter the fashion industry as a whole? What is the vision for the 3D prototyping in the industry for different players (vendors, managers, users, academics)?

1.3 Outline

This thesis is outlined as follows:

Chapter 2 describes the technologies in the Life Cycle of Clothing Products from Pre-Production, to Manufacturing, PLM, Retail and even smart materials. In this chapter the integration of these technologies with the digital prototyping process is discussed.

In **Chapter 3** we first outline the traditional garment sample development process, followed by the problems the industry faces today with the change of business models. The approach to the problem along with the methodology of the research is being explained in section 3.3 and the in depth analysis of the two different processes: the 2D and the 3D. The chapter concludes with section 3.5, trying to investigate the future of the physical sample regarding the virtual one and what remains to be seen on the 2D CAD systems in the fashion industry.

Chapter 4 extends the main focus of this research; Virtualization as an Integral Part of the Fashion Product Development. We present the outcomes of the primary collected data; interviewees were called to share their experiences, answer questions, examine & criticise the existing tools and help the investigation study to dig deeper into the characteristics of these technologies, the way they affect the apparel product development process and see if the hypothesis stated by the vendor side (3D design and visualization features is now an important part of the revolution in digital design and production technology for apparel manufacturers) is established by the experienced users of 3D, the independent consultants of the industry and the academic researchers.

In **Chapter 5** we investigate the relationship between CSR and Collective Actions on Sustainability and the environmental impact of the new model of fast and accelerating fashion. Section 5.3 shows how new technology solutions like PLM (Product Lifecycle Management), 3D visualisation or 3D prototyping can work with and across supply-chain partners to reduce the environmental footprint of their processes. In section 5.4 we conceptualise a new apparel product development model, encompassing various digital tools which aim at addressing fit problems, extending the useful life of clothes and reducing the environmental impact of clothing in use through design and services.

Chapter 6 explains what IoT represents and attempts to understand how IoT can support Fashion Design, Development and procurement as well as manufacturing comparing to conclusions drawn from Chapter 4 on the full adaptation of Virtualization technology as an integral part of the fashion product development.

Finally, **Chapter 7** concludes the thesis investigating if 3D virtual prototyping will conquer the fashion and clothing industry by becoming a mainstream tool or not and presents the vision of this highly promising technology from big fashion corporations and avenues of future work.

2

Technology in the Life Cycle of Clothing Products

Background

2

Technology in the Life Cycle of Clothing Products

Background

Technology has become a fundamental tool for any fashion or apparel company that aims to remain competitive in today's market and can be a powerful catalyst for change. Although for the most part of the last ten to fifteen years fashion has ignored technology, experts expect a radically different landscape in fashion. It is argued that present-day ready-to-wear technologies will presumably give way to computer-aided custom manufacturing (McLaud, 2010). This section presents the technologies in the Life Cycle of Clothing Products from Pre-Production, to Manufacturing, PLM, Retail and even smart materials. In this chapter the integration of these technologies with the digital prototyping process will be discussed.

Gerber Technologies (Gerber, 2016) points that the industry is going through a digital design and production revolution with six key digital trends in apparel design, management and production:

1. Cloud Computing for Apparel Companies:
Eliminating fixed IT overhead costs and providing virtually unlimited, scalable IT resources.

2. Product Lifecycle Management (PLM) Systems:
New Cloud-Based PLM stream lines, Line planning and Project Management for apparel makers of all sizes.

3. Mobile devices:
Making fashion easy to buy from every smartphone.

4. 3D design and Visualization:
Faster design and sampling iterations for lower cost and faster time-to-market.

5–6. The "Internet of Things" (IoT) and the smart factory:
Making machines smarter and more connected to increase efficiencies in apparel production.

2.1 Customized Clothing and Pre-Production Technologies

The clothing industry has become intent on utilising the latest technology in order to maintain competitiveness. Pre-Production technologies were first to being adopted, offering competitive advantage to small and large apparel companies (Loker & Oh, 2002). At the same time, consumers seek affordable products and services that are customised to their unique needs (Kotler, 1997; Bart and Boyton, 1998; Simmons and Istook, 2003). Mass customisation was seen as a key business principle of the twenty-first century competitive world (Fontana et al, 2005). It is believed, even lately, that customized products can differentiate a brand while elevating customer loyalty and engagement.

While brands across many categories leverage customization for marketing, at the same time customisation is most developed as a serious business in the Sportswear category, exemplified by Genius brands like Nike and Adidas.

While a handful of established brands across categories do some form of customization, Sportswear and Fashion have the highest levels of implementation.

Since new technologies and manufacturing, in closer proximity to the customer, is the key to wider adoption of customisation this section is dedicated as a literate review to these new technologies emerging to developments in the area of information technology, built on the traditional functions in order to offer a new way of using the systems of design, pattern and product development (Apeagyei & Otieno, 2005).

2.1.1 Digital Textile & Fashion Design

Mass manufacturing creates problems throughout the apparel's manufacturing supply chain, and especially when sourcing patterned fabrics and textiles. Long lead times and relatively high production runs are often required for silkscreen and other traditional fabric printing methods, and despite more accurate sales forecasting methods, apparel manufacturers always bear the extra costs or lost sales which result from producing either too much or too little material for their lines (Gerber Technology, 2016).

Digital textile printing is relying on efficient digital colour communication. Consistency and quality of colour are perceived as value-adding or value-defining properties of the fashion product (Adho, 2008).

Although the management of digital colour in the Clothing industry has been around for many years, it has been only in recent years that commercial systems have provided integrated solutions linking all the parties involved in the supply chain like designers, buyers and technologists. It has become possible to rethink the whole process of product development by specifying colour digitally at the outset of the product development process. According to (Tyler, 2011), digital printing of textile materials can provide sample lengths of the right colour (and visual texture) for prototyping and photo shoots. This offers the possibility of shortening lead times for product development and maintaining confidentiality about products until decisions to order bulk have been made. (Wentzel, 2002) in particular believes that digital technologies allow fabric print designers to work concurrently with apparel designers. Computer-aided colour matching and textile design systems can provide very appropriate results in the early stages of textile design and approval processes (Fig. 2.1.1a).

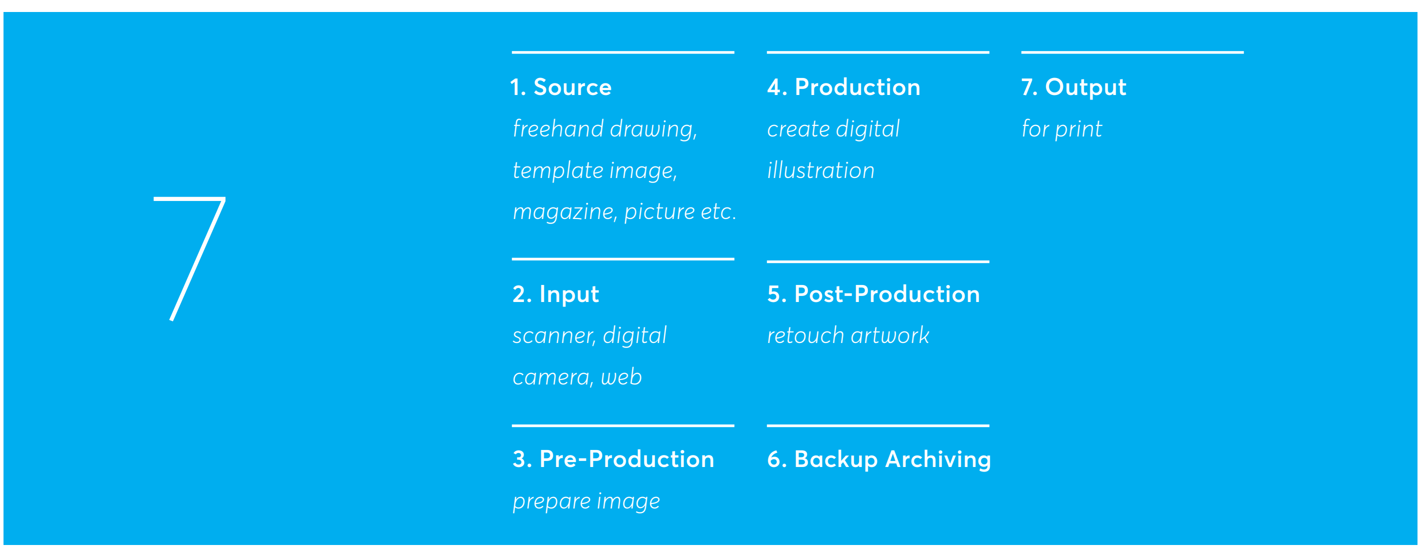


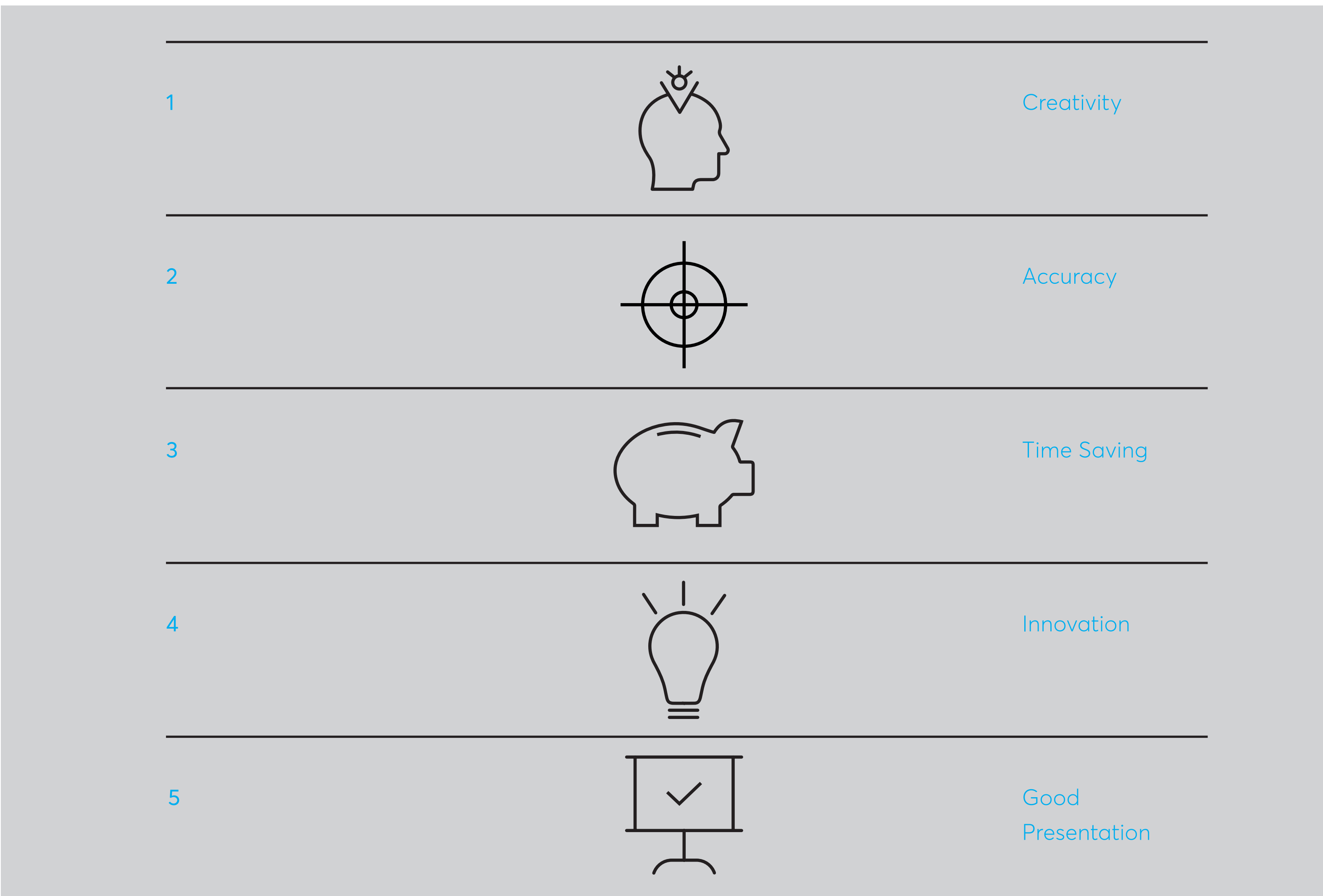
Figure 2.1.1a
Key Stages in Digital Fashion Illustration *Source: Author*

Figure 2.1.1b
Wash Pattern Swatch for a denim jeans illustration
Source: Centre & Vereker (2011) p.153

If a new fabric print can be simulated on screen in minutes and in the design room in less than 24 hours, then the time-consuming task of developing samples is greatly reduced. In another study, (Campbell, 2008), it is predicted that digital textile printing will continue to provide a simplification of the path from apparel specification through to the manufacturing of finished product and, at the same time, will help to meet the trend of vast customization.

Accessible image-manipulation tools such as Adobe Photoshop and Illustrator and the explosion of media platforms from which any budding fashion illustrator can experiment, have grown in size and number and so has the need for more visual content (Tallon, 2008). Another added advantage of these popular and economical graphics software is that they are compatible with powerful CAD apparel and textile suites produced by Optitex, Lectra, Gerber and so on. There are also specialist applications for fashion and textile design that help designers to produce different colour ways for textile designs, create different repeat patterns, develop knitwear designs, and create technical drawings (Gaimster, 2015). These systems are often accompanied with libraries of developed flat line renderings, knit and weave simulations usually imposed over sketches to show texture and dimension (Fig. 2.1.1b). Technology tools for fashion design can be used not only to develop a fashion collection but also for storyboards, line presentations and many other sales and communication tools (Fig. 2.1.1c).

Figure 2.1.1c
CAD Fashion Design Benefits



2.1.2 CAD Pattern Making Systems

As mentioned in Chapter 1, the clothing industry is the most skilled labour-dependent industry and any cost saving through new computer-aided design (CAD) technologies has become a requirement in gaining a competitive advantage.

Garment CAD technology is the use of computer as a tool to assist the design process of a garment production and the basis for the process of integration (Forza, 2010). It is given that CAD is a mainstream tool and companies that hope to compete in the fashion marketplace, especially at the mass level, cannot prosper without some level of CAD technology, if different parties involved want to interact at a distance, exchanging and sharing information useful for developing the products required. Furthermore, body scanning, virtual try-on, CAD and manufacturing (CAM) technologies have become more compatible and can now accommodate mass-customized clothing specific to individuals and target markets (Ashdown, 2014). Compared to other mechanical product, garment CAD has to address some special issues:

Instead of using rigid solid objects, fashion industry deals with soft material with low bending stiffness

The conventional assembly methods of other industries do not apply to the product of a garment where some parts like collar, sleeve, are assembled together following specific pattern-making rules *(Liu et al, 2010)*

Patterns are created to construct a prototype garment on a fit model using sizing systems, grading rules and general specifications. Many of the problems encountered by apparel companies can be traced to this dependence on sizes that are proportionally developed based on one fit model *(Ashdown, 2014)*

Garment industry, depends on 2D patterns for manufacturing but the quality of fit is evaluated on 3D human models. Based on these observations, garment CAD is a unique research area that has attracted considerable attentions *(Luo & Yuen, 2005; Apeagyei & Otieno, 2007; Daanen & Hong, 2008; Liu et al, 2010)*

2.1.2.1 Pattern Generation to Custom-Design Clothing

The clothing industry eventually needs 2D patterns to manufacture garments. As previously mentioned though, garment is a special soft product whose fitting can only be judged when fitted onto a 3D body. The industry has been adopting digital 3D technologies applied to try-on stages by using body scanners and are now foreseen fitting of tailor-made garments. According to (Istook, 2002), an essential key to the use of these enabling technologies is the ability of Computer-Aided Design (CAD) systems to integrate measurement information and make changes to patterns, as necessary, without permanently changing the basic, original garment pattern. (Hu et al, 2008), proposed an interactive co-evolutionary CAD system for GPD (ICE-GCAD) because they believed traditional CAD (Computer-Aided Design) methods in garment pattern design (GPD) fail to utilise the knowledge of experts for inexperienced designers (Fig.2.1.2.1a).

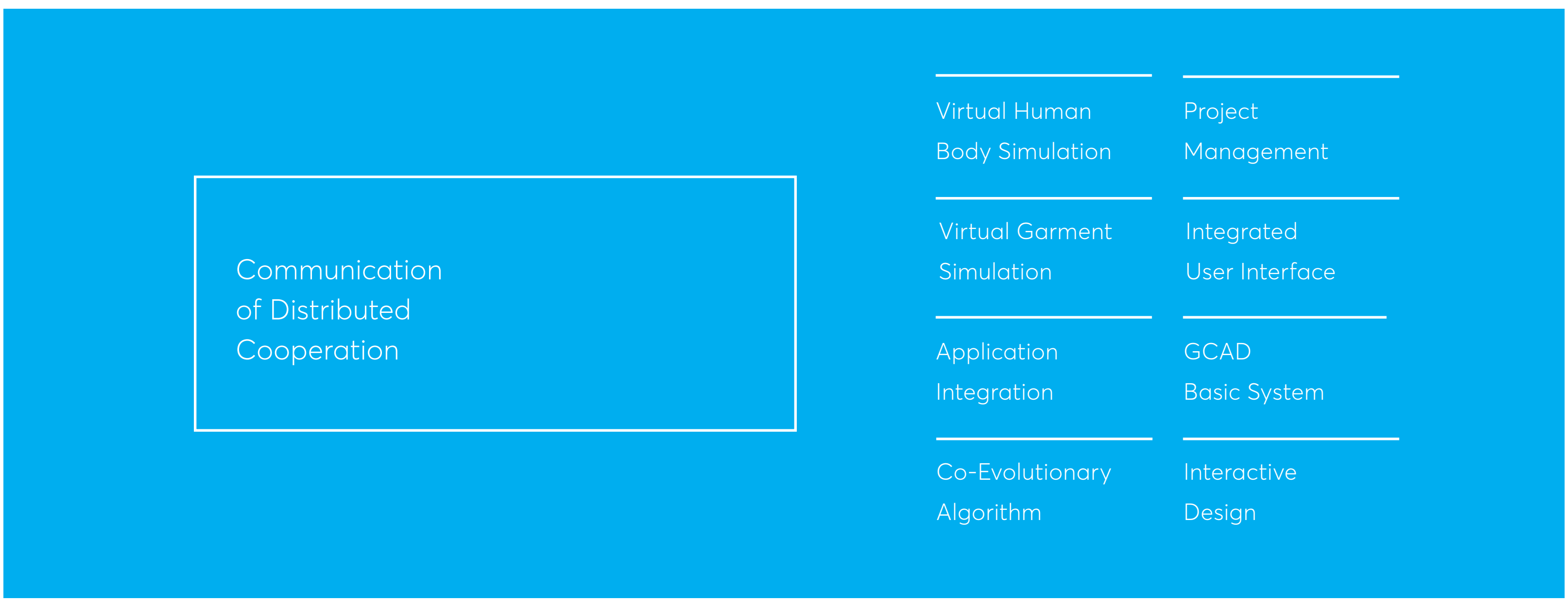


Figure 2.1.2.1a
Functionality Model of Interactive Co-Evolutionary-GCAD
Source: Adapted from (Hu et al, 2008)

Moreover, the study of (Fang et al, 2008) aimed to reduce the time and human resource costs involved in the process of garment development and to pursue the objectives of fittingness of clothing and the display of graceful figures by reversing design procedures. They presented a knowledge-based system with a flattening method for developing 2D basic patterns from 3D designed garments. In garment flattening, computer-aided tools use colour-index mapping to help visualise the stretch by different colours inside the flatten patterns. Usually hot colour corresponds to large stretch and cold colour to low stretch (Fig. 2.1.2.1b).

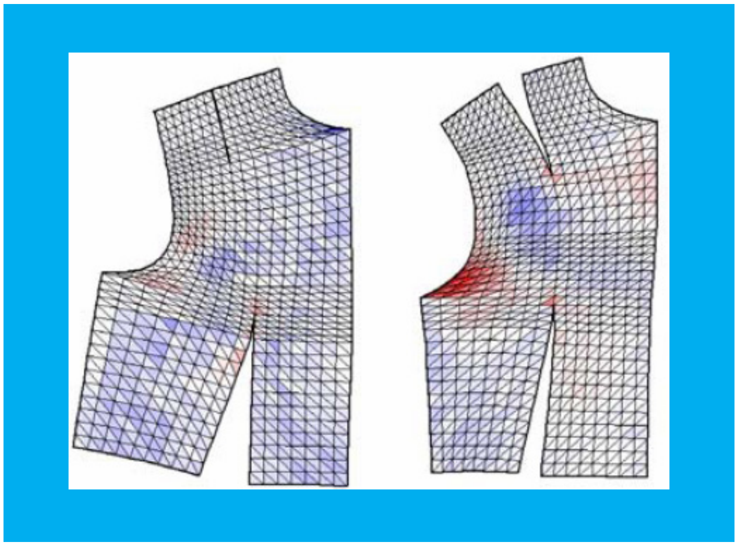


Figure 2.1.2.1b
Functionality Model of Interactive Co-Evolutionary-GCAD
Source: Hu et al, 2008

In these 3D computer-aided garment design systems triangulated cloth patterns are used and mapped onto a mannequin model by minimizing a quadratic energy function.Several studies have been taken place for 2D-to-3D sewing and fitting (Volino, 2005).

2.1.3 Draping and Fitting Evaluation

Another critically important parameter in the application of body scanning, mass customisation, computer-aided design and computer-aided manufacturing (CAD-CAM) and automatic pattern making to clothing design and manufacturing is drape modelling; drape and the dominant role of fabric mechanical properties. In recent years, the most significant developments have been the empirical prediction and modelling of drape as well as the move towards 3D design, simulation and virtual modelling (3D virtual prototyping). Several 3D fashion design systems have been developed with online interface that take several sizes and redrape them on a custom model to allow for trying on clothes online. These interfaces enable the designer to 'drape and validate' their design onto a computer generated mannequin or one built off a body scan of a fit model, taking into account technical information, fabric type, colour, drape, tensile, shearing, bending as well as the effect of seams (Fairhurst, 2008). (Volino, 2000; Volino et al, 2005) have proposed many deformable cloth models for efficient garment draping and animation with which the customers can visualise the realism of virtual try-on. In addition, fuzzy-logic systems have been developed and used to help to improve a wearer's perception of the fit of a garment and to achieve a balance between the style of garments and the comfort of the wearer (Chen, 2009). However, according to (Ngai, 2014) such a balance is difficult to achieve using existing pattern generation methods because these methods cannot provide suitable estimations. The study of (Tao & Bruniaux, 2013) argues that these previous works were dedicated to the development in the pure information technique but ignored the basics of the garment design which should consider the comfort ease and fitting with respect to the body shape in cyberspace. All these research project and studies as well as several software solutions including, Optitex, Browzwear, Clo3D, Tukatech and Lectra which enable visualisation of garments on three-dimensional parametric avatars, represent that 3D mass customisation is the future of the clothing industry, increasing greatly the potential of creation (Chapter 4).

2.1.4 Style Editing

In the traditional fashion product development cycle, designers often adjust 2D patterns to produce clothing with better fit for individual customers, who often do not have ‘ideal’ body shape and possess with a few ‘abnormalities’ in one or two areas of the body. In addition to 2D pattern alteration, tools are developed for 3D based interactive style editing. Users can drag the feature curve or boundary of the 3D garment directly to alter the garment size. In most CAD applications, freeform deformation is used for 3D garment editing, the edited results cannot be accurately reflected on 2D patterns, because distortion free flattening method is still not yet available. As in the case of 2D digital style editing where designers use specialist software, there is also growth using standard off-the-self software such as Maya and Poser as well as Adobe’s Photoshop to do modelling using additional software plugins (Burke & Sinclair, 2015). (Meng et al, 2012), proposed a novel method for 3D-based editing allowing direct style editing for fit improvement in 3D space, and directly projecting results on the pattern alteration in 2D plane.

2.1.5 Body Scanning

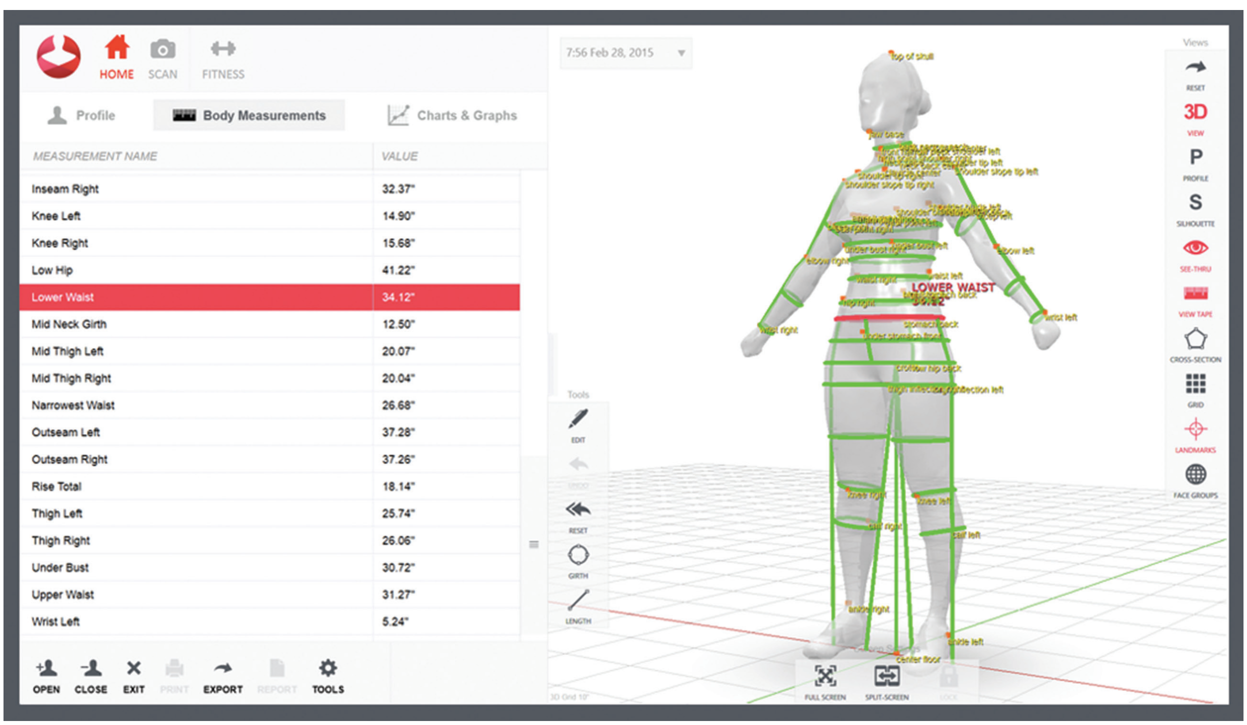
Three-dimensional (3D) body scanners have significant potential for the apparel industry. This technology provides speedy, consistent, and accurate data to redefine apparel sizing systems so that they more closely match the current shapes of human bodies (Ashdown et al., 2004; Istook and Hwang, 2001). Body scanning can precisely measure consumers and analyze those results to better represent their target audience in future clothes by better representing them in a ready-to-wear system. Optitex presenting 5 digital trends to transform fashion (Optitex, 2016) pinpoints Mass Customisation as one of the five and although there are still obstacles and more research to be done in the field of body scanning it states that this technology will allow designers and retailers to create better product, with better fit by understanding their consumers.

The price of body scanners has come down by 50–75% with improved portability (Senanayake, 2015). Numerous studies (Ashdown et al., 2004; Loker et al., 2005; Istook,

Figure 2.1.5a
SizeGermany fashion manikins (Human Solutions, 2015)

Figure 2.1.5b
3D body shape and measurement visualization (Styku, 2016)

2008; D'Apuzzo, 2009) have demonstrated the significance and value of using 3D technology to address the challenges associated with garment sizing and fit worldwide. Manufacturers are now able to develop protocols for scanning large numbers of their population to collect body shape and size data, quickly and non-intrusively (Pandarum & Yu, 2015). Several companies specialise in 3D body scanning offering accurate methods of measurement, allowing at the same time the integration of size & fit data into the development processes (Anthroscan by Human Solutions, SizeStream, Styku, Fig. 2.1.5a & Fig. 2.1.5b).



These body scanners enable many competitive advantages like:

High quality in size and fit
More profitability in the creation of customised clothing
New ways of customer bonding in the retail trade

Other initiatives also integrate complex systems thinking and cutting edge research and innovation in order to reduce technology and market silos as well as to accelerate the creation of shared value in an open and collaborative environment. IEEE, the world's largest professional organization dedicated to advancing technology for humanity, announced the launch of a new IEEE Standards Association (IEEE-SA) Industry Connections (IC) program aimed at bringing together diverse stakeholders from across technology, retail, research and standards development to build thought leadership around 3D body processing technology standards; BodyLabs, Browzwear, Gerber Technology, Intel Optitex and SizeStream are some of the participants[1].

However, body scanning is not the full solution to the fit problem, but can assist in a way that can provide not only body measurements but also other solutions such as 3D digital body models for e-fitting and garment-size prediction for consumers. As soon as mobile devices include 3D sensors in the near future, there is expected to be an influx of body-scanning applications for consumers to use. Apparel companies will benefit from this "mobile body scanning" capability for size-prediction applications and supplying correct-fitting clothing to consumers. It is also expected that the scanning applications can be accessed through subscription systems (Senanayake, 2015). Indeed, experts report that the depth-sensing time-of-flight camera technology is already showing up in the next generation of smartphones. Google's Project Tango[2] is an example.

In a personal interview with an academic professor specialised in body-scanning and sizing research, the optimism although restrained can be discovered between words:

[1] http://standards.ieee.org/develop/indconn/3d/bodyprocessing.html (accessed 05/05/2016)

[2] Google's Project Tango is a technology platform that uses advanced computer vision, depth sensing, and motion tracking to create on-screen 3D experiences, allowing users to explore their physical environments via their device.Using the sensor in the device, Project Tango devices can also capture the 3D dimensions of the room, giving measurements that can be used to help you when shopping for furniture or decorations. http://news.lenovo.com/news-releases/lenovo-and-google-partner-on-new-project-tango-device.htm (accessed 01/02/2016)

[3] Alvanon: The Apparel Fit Expert multi-national company and the world's largest producer of fit mannequins. http://alvanon.com/ (accessed 21/10/2015)

"Some things have changed. It's just not been at the level of the consumer and in the way we were expecting it to happen. The apparel industry now makes use of the body scanning data either from purchasing data or through third parties that priorly have analysed data. All the major manufacturers now have used body scanning data in some way to improve their size range. But we don't see that—it is some kind of behind the scenes. Body Scanning has had a major impact on the development of dress forms like Alvanon[3] who has used that data to create dress forms. So these are couple of areas. There are some small companies all over the world who use body scanners to do custom clothing but none of them appear to major manufacturers. Mass customisation for sizing and fit has never really taken hold that there is a new way to consider so we will see what happens" (Ashdown, Appendix 1)

2.1.6 Virtual Try-On

The fashion industry welcomes the concept of designing the garment directly in 3D. The aim is to have more flexibility in the way the samples and prototypes are being made, by reducing the prototyping cycle time and significantly simplify the process that currently relies on physical samples and fit sessions.

Very early-on, several researchers saw a great potential for cloth simulation with modelling tools of clothing allowing fashion designers to experiment easily with a variety of fabrics and patterns on a 3D dynamic virtual mannequin before the actual garment is manufactured (Volino & Thalmann, 2000). Once the design is complete, it can be sent to a computer-controlled fabrication machine for weaving the cloth and cutting out the appropriate patterns. Potential buyers may even try the virtual garment before actually ordering it, using an augmented reality system. In this way, customized clothing can be designed and made in an automatic fashion. Fontana et al (2005) presented a physics-based system for virtual cloth design and simulation expressly conceived for design purposes. They discussed that integration of these models within CAD systems for garment design leads to highly accurate cloth shape results for virtual prototyping and quality evaluation tasks.

However, the current garment development process should not be changed completely, but instead embrace the new 3D practical tools and make them fit in the existing development process.

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 successful control of communication, final product and delivery schedule across global partners (Walter et al, 2009).

Walter et al (2009), developed a collaborative virtual prototyping platform linking 3D CAD to traditional 2D CAD and PDM (Product Data Management) systems. With this platform, they provide an online access to specialised services, such as a fabrics library, an online cost estimation facility, and a real-time interactive animation service (animated virtual try-on of different garment sizes on different body sizes and shapes). Their objective was to reduce 'time to-design', reduce prototyping costs and provide an efficient e-collaboration environment for multiple actors involved in product development.

"Virtual prototyping (VP) is a process used for shortening the time to market and reducing the product cost. It makes use of a digital model, called virtual prototype, for testing and evaluating the specific characteristics of a product and for simulating the manufacturing processes in a computational environment. Therefore, errors concerning design, manufacturing and production planning can be detected in a compressed time frame before big investments are committed" (Raffaeli & Germani, 2010)

Although, as it was mentioned above, the fashion industry is slow to embrace the virtual modelling due to the challenging material of the fabric, many see the revolution coming. The developers of Fashion 3D modelling systems offer new and more convenient tools and the effect of reality is becoming more and more convincing. Although computer systems significantly facilitate the development of a product, the knowledge and skill of the user are still very important. The main problems are connected with defining the connectable layers, determination of tuck-up and roll-up parts of a garment, characterisation of the multi-coloristic qualities of a fabric, the thickness of layers and the position of padding (Vilumsone, 2012).

As it was mentioned in the beginning of this chapter, 3D design and Visualization is highlighted as one of the six most influential trends in apparel design, management and production according to Gerber Technologies (Gerber, 2016)

2.1.6.1 Intelligent Design Systems

The intelligent garment design system is based on the technology of an intelligent interface between human and computer, the technology of the knowledge base, the technology of illation mechanism and the technology of 3D modelling. In the research study of (Liu & Geng, 2003) this new system changes the conventional design process greatly in inputs, outputs and processes as shown in the following Figures.

The difference of the conventional CAD fashion design system to the garment intelligent design system is the number of steps: The first (Fig. 2.1.6.1a) needs five steps: The designer lays out a definite style with design system and sends it to the Creation leader to evaluate it. Then the pattern maker develops the digital pattern for the chosen design and outputs a 2D pattern. Skilled workers make the sample and after the iterations the final output of the pattern is ready.

With the intelligent design system (Fig. 2.1.6.1b) the steps are reduced to three: A general user enters his semantic requirements to drive the intelligent system, the system generates a 3D design, the consumer evaluates it and accepts it or not. No need for a sample dress, due to the fact that the user can modify the style directly on screen. Finally the output of the ready-to-wear pattern is set.

Figure 2.1.6.1a
The conventional garment CAD process

Figure 2.1.6.1b
The garment intelligent CAD process

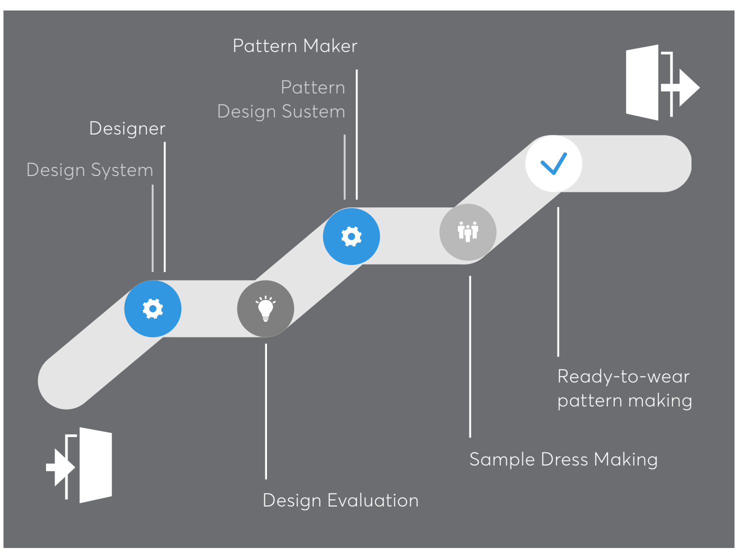


Figure 2.1.6.1a

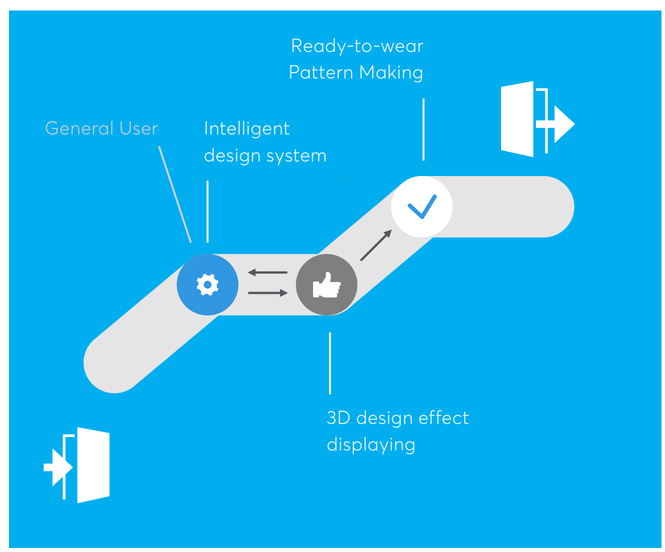


Figure 2.1.6.1b

2.2 Garment Manufacturing Technologies

Traditionally, the apparel manufacturing process has been performed by production workers who perform the cutting, sewing and other operations in an assembly line. In spite of the technical advancements, the apparel industry still remains as a labour-intensive unit.

Although most supply chain models are linear, documenting the forward movement of materials through various processes to become products in the hands of consumers (Tyler, 2008), fast-fashion models need a closed-loop systems approach. Retailing is actively involved in assessing consumer demand. The characteristics of the activities in the design center, in the manufacturing plants and in the distribution centre are all associated with the just-in-time (JIT) philosophy for manufacturing systems. Factories have to be lean, mean and, above all, disciplined environments in order to survive in an increasingly competitive world (Hayes & McLoughlin, 2008). LEAPFROG Project's[4] vision was an innovative concept for garment manufacturing, comprising a holistic, general production-line from single-ply cutting, automatic transport to sewing processes with robotic 3D sewing and 2D sewing machines (Moll et al, 2009) (Fig.2.2a).

Such developments involving the increasing use of robotics to transport components and materials within the plant, help in improving production efficiency. However, according to (Nayak et al, 2015) the apparel industry and especially sewing technology has remained significantly less automated compared to many other manufacturing industries.

Adidas though, has set-up the first pilot SPEEDFACTORY[5,6], in Germany, combining the design and development of sporting goods with an automated, decentralised and flexible manufacturing process (Fig. 2.2b). This flexibility opens doors for Adidas to be much closer to the market and to where the consumer is, cutting out the phase where the product needs to be transported.

[4] LEAPFROG: the biggest ever EU-funded research project in the clothing industry, attempted to overcome the 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 (Walter et al, 2009)

[5] http://www.adidas-group.com/en/media/news-archive/press-releases/2015/adidas-first-speed-factory-lands-germany/ (accessed 07/01/2016)

[6] Speedfactory is a research project under the umbrella of the German Government. The aim is to shape the future of manufacturing and come up with innovative products as well as new production technologies & efficiencies while looking into consumer needs, speed, flexibility, and sustainability. Speedfactory has been selected to be part of the national "Autonomic for Industry 4.0" programme. This programme contributes to realising the high-tech strategy 2020 of the Federal Republic of Germany and focuses on a new era of manufacturing by combining state-of-the-art information and communication technologies (ICT) with industrial production, innovative products or skill-intensive electronic services. The objective is to push the development of autonomic systems to establish Germany as a leading industrial base for new and forward-looking internet-based technologies. http://www.fortiss.org/en/research/projects/speedfactory/

Figure 2.2a
Concept for innovative holistic manufacturing process (Moll et al, 2009)

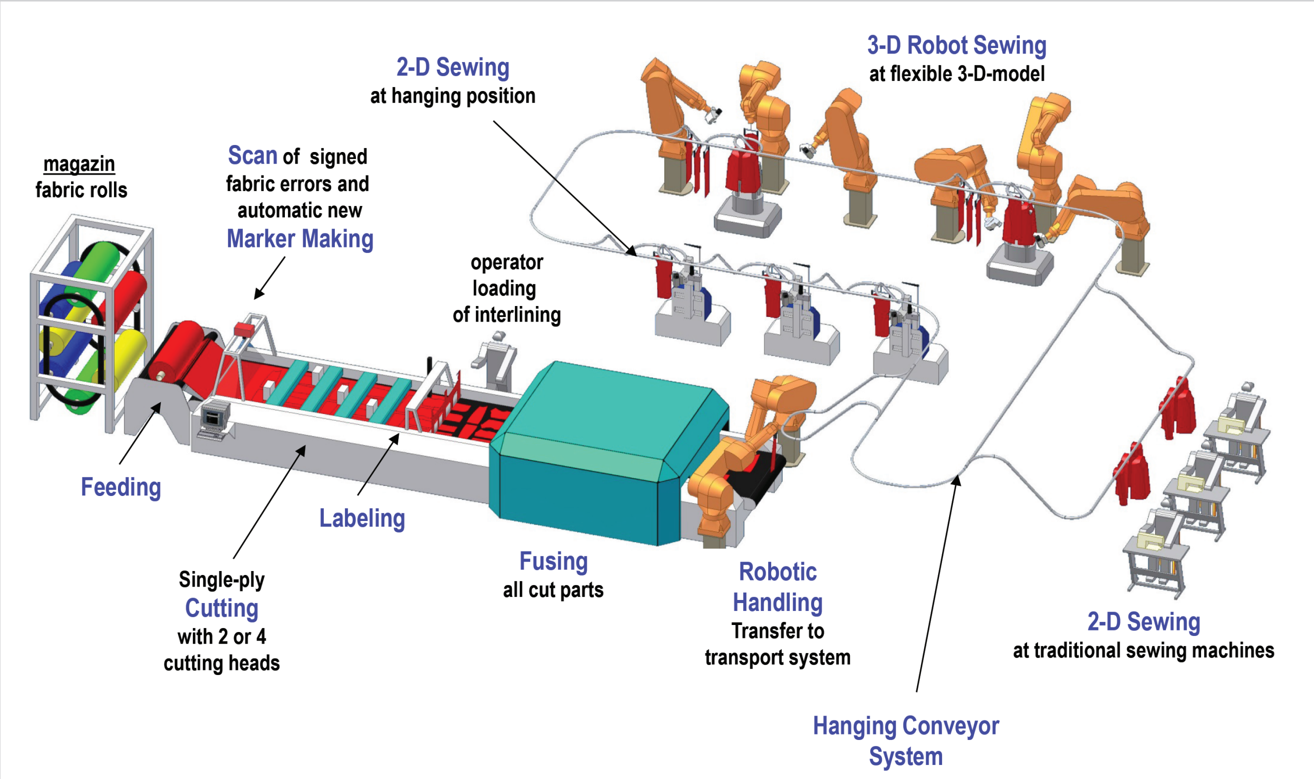


Figure 2.2b
Intelligent robotic technology offering high performance quality & unique design to the shoes
Source: Robotrabbi, 2015

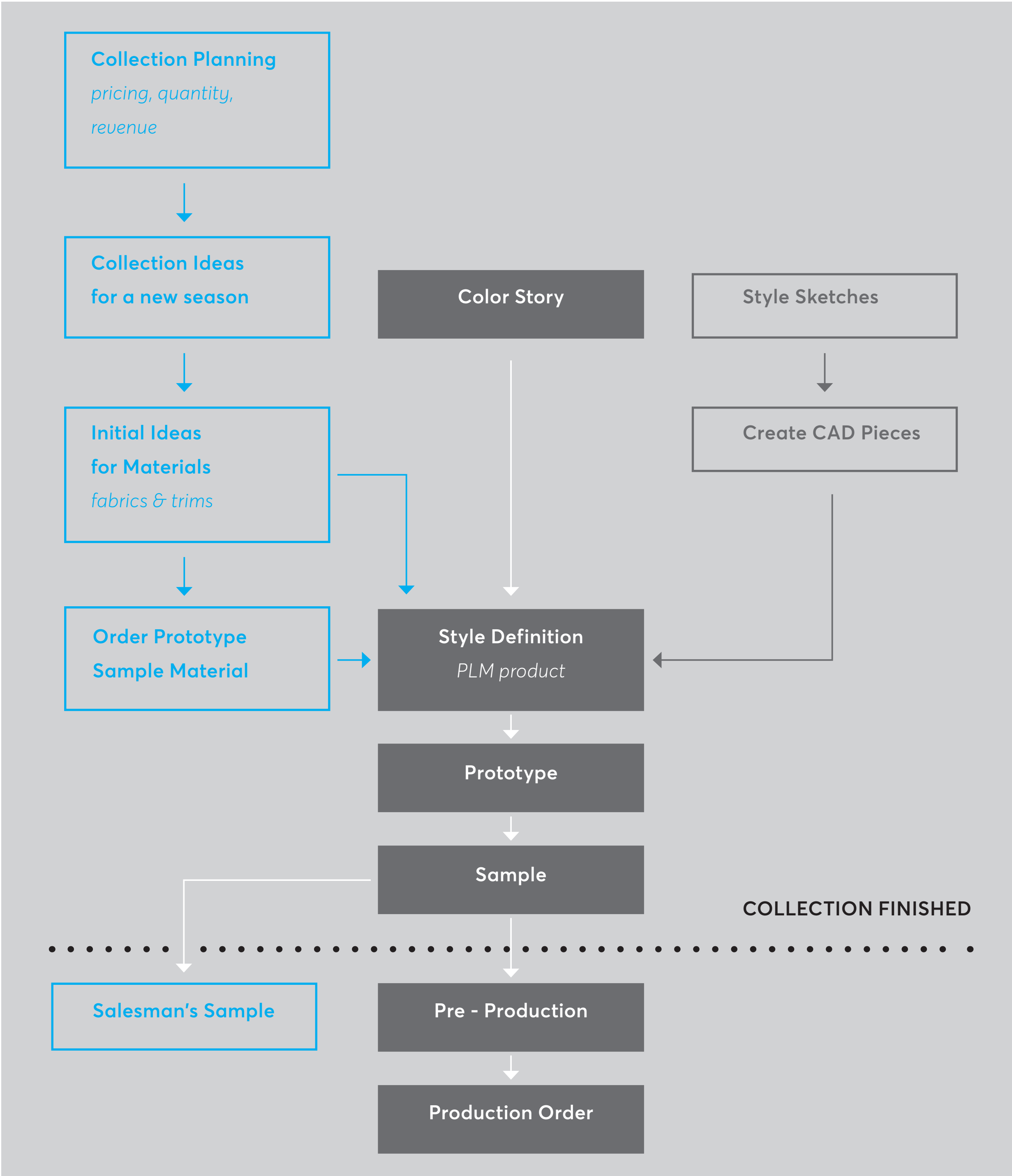


Figure 2.3
PLM links all process involved parties

2.3 PLM (Product Lifecycle Management)

The new changes to the Fashion Week calendars, impact to the core foundation of the way many companies work from creative inspiration to product development, technical design, merchandising, sourcing, sales, and marketing. Historically, many of those companies used spreadsheets to manage their information all through the previous activities. However, spreadsheets lack the functionality and data structure needed to collaborate and communicate to conduct this fast-moving consumer-driven industry (Senanayake, M., 2015). Fashion, retail, outdoor and footwear are all extremely complex, each product having widely varying lead time and necessitating large teams to get to market. All the design, development, production, and selling activities revolve around a standard timeframe. Working with a consistent platform from inspiration through manufacture can help to unlock significant savings in material usage (Lectra, 2015).

According to Susan Olivier[7], a decade ago, PLM (or perhaps PDM in those days) was all about the data, and users were happy to find they had a low-resolution thumbnail to accompany that information. Today, fashion businesses are moving more towards a model-driven approach, rather than purely data-driven one (Olivier, 2015). PLM applications are designed to concurrently support brands and retailers to keep pace with changing lead times, so that creative concepts can be turned into commercial products quickly. For many vendor companies PLM is the backbone of the development process, providing a seamless process, from the first draft to the store. Digital technologies, such as cloud computing, PLM systems, 3D visualisation and digital apparel printing according to Gerber Technologies (Gerber, 2016), can help fashion and apparel businesses successfully face the added challenges of working within global supply chains. The implementation of Product Life-cycle Management (PLM) allows successful integration across the fashion enterprise: it is not just a technology, but a strategic business approach that integrates people, processes, business systems and information (d'Avolio et al, 2015) (Fig. 2.3).

[7] Susan Olivier, VP Consumer Goods & Retail, Dassault Systemes, interview at WhichPLM

Whether companies work in 2D or 3D environment need to have available that single version of the truth of a 'digital referential" model of product to all the right people within an organisation. Solutions like CentricSoftware[8], Dassault Systems[9], Gerber Yunique PLM[10], Human Solutions GoLive PLM[11], Infor's Fashion PLM[12], Koppermann's PLM[13], Lectra fashion PLM[14], NGC's PLM[15], PTC's FlexPLM[16], TXT PLM[17] and VisualPLM[18] are proposed by the available vendors according to the 5th edition of Which PLM Report (WhichPLM, 2015).

The reasons that PLM for fashion has been able to progress to the stage where it's widely considered to be of equal importance to ERP, perhaps the most significant investment that any brand or retailer will make in information technology are two (Harrop, 2015):

1. **Better product**
2. **More confident customers**

The primary barrier to PLM adoption remains cost, until cost-effective cloud deployments are perfected. Those cloud-based PLM systems move planning, calendar development and project management tasks away from using multiple, haphazardly organised Excel spreadsheets and hard-to-process databases to a readily accessible, easy-to-use system that can be securely accessed by a company's design, production, sales and financial teams (Gerber, 2016).

Today, the unity of 3D tools and PLM is ready to transform the fashion industry to a far greater extent than most people realise. With rapid advancements in simulation fidelity, visual quality, user experience, and technical capability being demonstrated, these tools have already begun to change the way that garments, are designed, developed, manufactured and sold. Mark Harrop (2015), says that no aspect of the modern, international product lifecycle will remain untouched once 3D crosses its own chasm something he and many other industry figures believe will happen incredibly quickly. 3D Visualisation and virtual prototype will be thoroughly examined through personal interviews in Chapter 4.

[8] www.centricsoftware.com

[9] www.3ds.com

[10] www.gerbertechnology.com

[11] www.human-solutions.com

[12] www.infor.com

[13] www.koppermann.com

[14] www.lectra.com

[15] www.ngcsoftware.com

[16] www.ptc.com

[17] www.txtretail.com

[18] www.visual-2000.com

2.4 Distribution & Retail

RFID, an innovative automatic identification technology, which identifies and gathers data without human intervention, or data entry (Wyld, 2006), has been deployed to improve supply chain processes such as handling materials with better efficiency, managing assets more effectively, and improving availability of products (Reyes and Jaska, 2006). Indeed, the value of RFID technology has been particularly visible in Fashion Supply Chains (FSCs), as the fashion industry, as many times reported, is characterized by a wide assortment of products, short life-cycles, high seasonality, high volatility, high-impulse purchasing and complicated distribution and logistics operations (Christopher et al., 2004; Castelli and Brun, 2010). However, through the industry-academia projects reported in (Legani et al, 2010) research, it is confirmed that applications of RFID were more accessible in the downstream part of the network while still under research and of experimental nature in the upstream side.

Significant research studies have been conducted on the creation of Virtual Try-On experience platforms. (Stylios et al, 2001) developed a system aiming to interface with global retailing for online parametric geometric 3D virtual human body modelling, image measurement and data management. MIRALab[19], presented an interactive, virtual shop where customers could view garments fitted onto their own virtual bodies and visualize made-to-measure clothes, animate them and visualize the cloth behavior (Protopsaltou et al, 2002). Non-sensor or sensor interactive technologies for clothes fitting rooms have been deployed by several retailers and large departments stores. Macy's, Nordstrom and Bloomingdales have employed the Magic Mirror[20], Levi's have employed online services like Intellifit[21] and MyShape (Begole et al, 2009). All these continually advanced virtual fitting technologies are comparable to seeing clothing on a personalised mannequin.

Whether it is mobile retail, interactive mirrors, interactive digital displays, retailers are innovating to offer experiences that integrate digital touchpoint in every step of the way (Cosco, 2016).

[19] MIRALab: Founded in 1989 and headed by the Professor Nadia Magnenat-Thalmann, MIRALab teams up around 20 researchers coming from as many different fields as Computer Science, Mathematics, Medicine, Telecommunications, Architecture, Fashion Design, Cognitive Science, Haptics, Augmented Reality, etc. This truly interdisciplinary group works in the field of Computer Graphics, Computer Animation and Virtual Worlds. The group works under the aegis of the Centre Universitaire Informatique (CUI), University of Geneva in Switzerland

[20] Magic Mirror allows a person trying on clothes to send video of himself to friends who can send back comments and vote (thumbs up/down). The Magic Mirror can also project a static image of an alternate garment onto the mirror allowing the person to see roughly how it might look on him.

[21] Intellifit, http://www.intellifit.com/Intellifit/Home.aspx

2.4.1 VR & AR

Consumers that purchase apparel online today base their purchase and size-selection decisions mostly on 2D photos of garments and sizing charts. Recognizing the insufficiency of this customer experience, e-tailers have begun to implement improved functionalities on their sites (Protopsaltou et al, 2002). Retailers have been dabbling in virtual fashion for a while using visual fitting rooms and body scanners like Me-ality[22] and TrueFit[23] with solutions for personalised fit, comfort and performance. Other solutions like Virtusize[24] or fits.me help online customers to find clothes that fit perfectly. At the same time these platforms promise delivered value to the brands which adopt them:

— Increased conversions

— Increased life time value

— Increased net proper score

— Decreased returns

— Increased average transaction value

— Increased customer loyalty

When it comes to Virtual Reality in the stores, customers would be able to see customised VR shops and product ranges, try items on and shop socially all while wearing a VR headset. In particular, according to Samsung, Goldman Sachs envisions VR retail software becoming a $500 million revenue opportunity by 2020, and ballooning to $1.6 billion by 2025. In its recent report, the company says VR is one of the technologies "retailers will have to invest in to serve their customers and keep ahead of their competition"[25].

22 http://www.me-ality.com/

23 https://www.truefit.com/

24 http://www.virtusize.com/

25 https://insights.samsung.com/2016/03/01/how-vr-at-retail-stores-is-reshaping-the-consumer-experience/

Tommy Hilfiger, the first to adopt VR at it's retail stores, announced that VR is part of the mission to elevate the shopping experience through digital innovation; these technological integrations in the retail space are evolving traditional brick-and-mortar set-ups and increasing opportunities for social engagement

In addition, retailers are looking at expanding VR together with AR, exploring the use of Microsoft Hololens, using a blend mixed reality with 3D holographic content from RCS and bringing both into the physical world. According to (Handson, 2016), this will give VR & AR holograms real-world context and scale, allowing customers to interact with both digital context and the world around them.

2.5 Smart materials Smart clothing Embedded Systems

In the field of textiles, innovation has resulted in a wide range of natural and synthetic fabrics that are lighter, smarter, multifunctional and with a wider range of engineered properties (Frumkin et al, 2012). Research on smart and intelligent textile began at the end of the 20th century, and it has made a quantum leap in the 21st century.

Wearable technology involves integration of electronics into clothing, watches and even bodies. Clothing and electronics have traditionally been separate industry sectors (Hurford, 2009) with completely different development timelines (Zimmermann, 2015) and different life cycles (Seymour, 2009). An electronic component may have an estimated life span of 3 years or more and a typical article of clothing might be disposed of after a couple of seasons. Making a workable integration between the two is a challenging preposition which results to a need of cross-disciplinary synergy between fields of fashion, design, and technology science with several suggested development process for smart clothing products. (Van Langenhove, 2004; Arivatum, 2005; Gilsoo, 2010; Sonderegger, 2010).

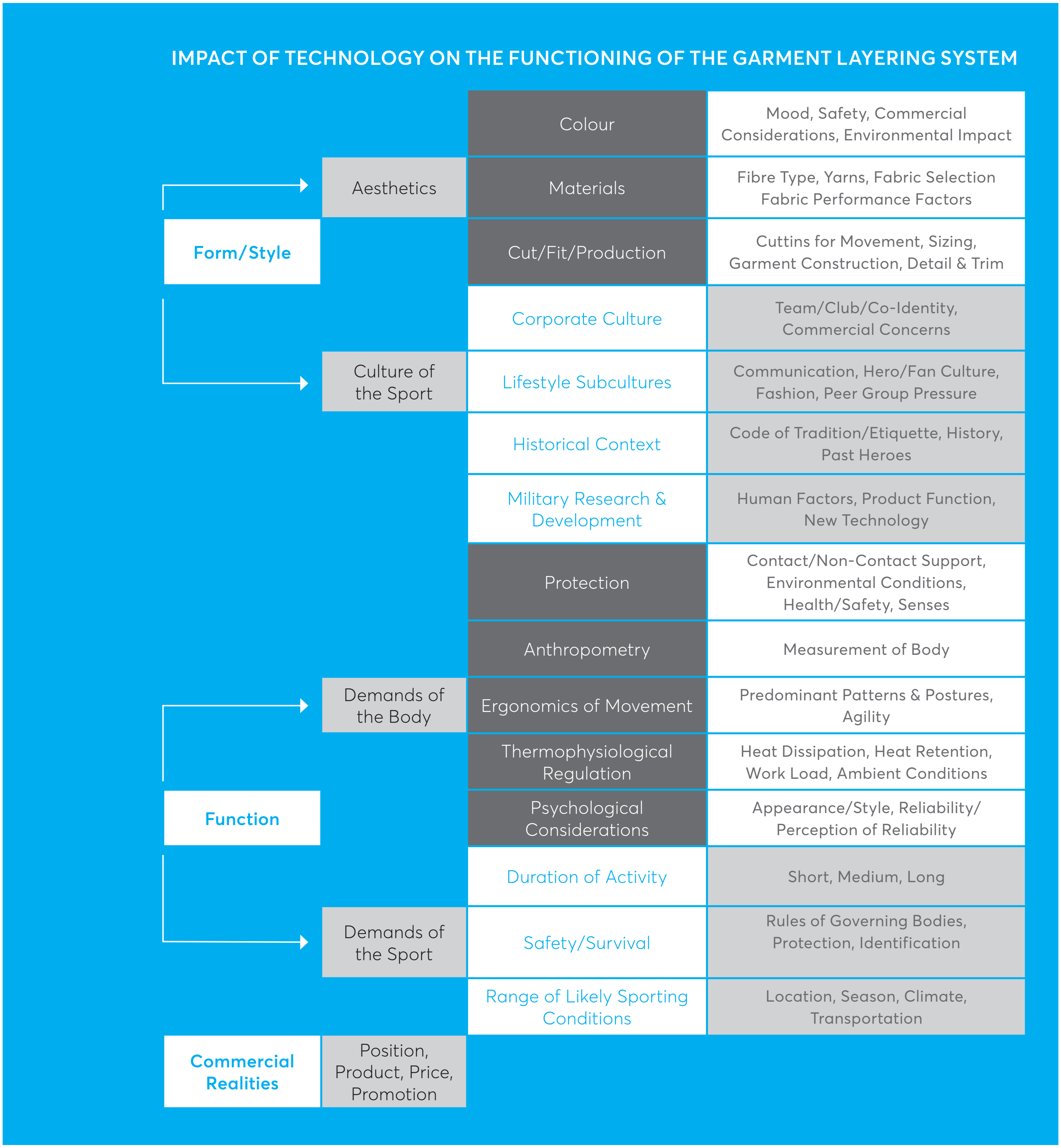

IMPACT OF TECHNOLOGY ON THE FUNCTIONING OF THE GARMENT LAYERING SYSTEM
Colour
Mood, Safety, Commercial Considerations, Environmental Impact
Aesthetics
Materials
Fibre Type, Yarns, Fabric Selection Fabric Performance Factors
Form/Style
Cut/Fit/Production
Cuttins for Movement, Sizing, Garment Construction, Detail & Trim
Corporate Culture
Team/Club/Co-Identity, Commercial Concerns
Culture of the Sport
Lifestyle Subcultures
Communication, Hero/Fan Culture, Fashion, Peer Group Pressure
Historical Context
Code of Tradition/Etiquette, History, Past Heroes
Military Research & Development
Human Factors, Product Function, New Technology
Protection
Contact/Non-Contact Support, Environmental Conditions, Health/Safety, Senses
Anthropometry
Measurement of Body
Demands of the Body
Ergonomics of Movement
Predominant Patterns & Postures, Agility
Thermophysiological Regulation
Heat Dissipation, Heat Retention, Work Load, Ambient Conditions
Function
Psychological Considerations
Appearance/Style, Reliability/ Perception of Reliability
Duration of Activity
Short, Medium, Long
Demands of the Sport
Safety/Survival
Rules of Governing Bodies, Protection, Identification
Range of Likely Sporting Conditions
Location, Season, Climate, Transportation
Commercial Realities
Position, Product, Price, Promotion

Figure 2.5a

Figure 2.5a
The start of a process tree for examining the co-design area of smart clothing and wearable technology
Source: McCann (2009) p.48

Figure 2.5b
Transformation of the TCF industry

In addition, garments are generally produced in the thousands versus electronic components, which are produced in significantly larger numbers for cost efficiency due to a much longer R&D phase. Other researchers like (Van Langenhove, 2004) also mentioned that smart clothing is a combination of new fabric technology and digital technology (Fig. 2.5a), which means that the clothes are made with new signal-transfer fabric technology with installed digital devices but they didn't focus on any roused problems.

Instead they concluded that this combination, meet all criteria of high-added value technology allowing transformation to a competitive high-tech industry (Fig. 2.5b): from resource-based towards knowledge-based; from quantity to quality; from mass-produced single-use products to manufactured-on-demand, multi-use and upgradable product-services; from "material and tangible" to "intangible" value-added products, processes and services. According to (Ji & Lee, 2010) these clothing products will eventually be essential to the near future lifestyle.

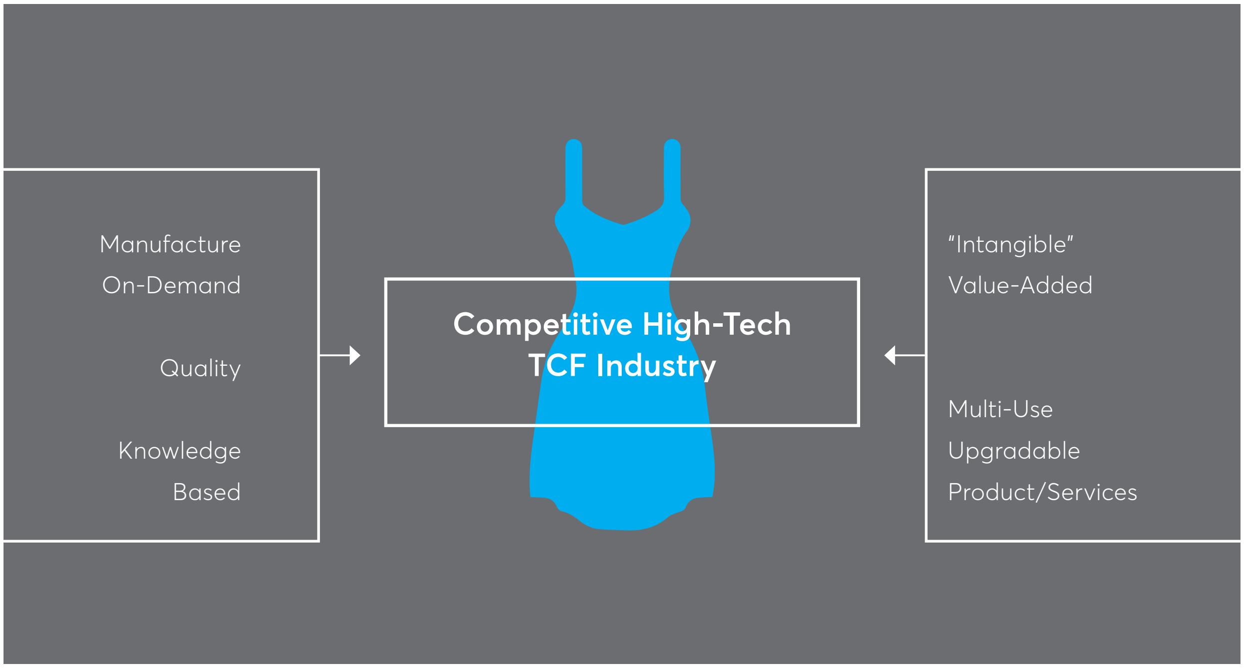


Figure 2.5b

2.5.1 Enabling & Emerging Technologies

As it has just been mentioned, smart clothing with embedded materials and systems is the convergence of the textile/clothing and digital industries. As the combination between these two industries brings large opportunities and benefit, many institutions, organisations, and enterprises have paid great attention and planned significant investments. It is expected that this integrated technology will proceed from block-based technology to embedded technology, and accordingly to move technology from textile converting to fibre level. Therefore, novel fibre materials such as ICPs and new technologies such as nanotechnology and electro spinning will play an important role in the next-generation material/technology (Gilsoo, 2010). More recently, according to a technology analyst (Hayward, 2015), wearable technology is part of a mega-trend involving integration of electronics into every aspect of our surroundings whether it is clothing watches or even our bodies themselves. New ‘made-for-wearable” sensors, (one of the needed integrated features to support and power them), enable a $5.5 billion market by 2025.

However, there are significant challenges in wearable technology prototyping: the “wearing" side related to softness and aesthetics, and the technology side related to functionality. On top of that, every part of technology made of textile material should be simplified, invisible, attractive and fashionable; otherwise technical components cannot be completely integrated into the clothes (Fig.2.5.1).

This is the reason why (Ugur, 2013) proposes prototyping process consisting of three parallel activities: electronics, garment making and interaction design; three activities strongly connected to each other. In particular, design-wise, advanced tools and materials are making the designer’s task even more complex. (Gilsoo, 2009) suggests a needed new product design model to enhance understanding about the work and communication with collaborators in order to create balanced products in function and aesthetics. Designers need to consider the real need and ease of use in terms of functionality, positioning, compatibility, maintenance and aftercare, and the clarity of the interface between the technology and the user (McCann, 2009).

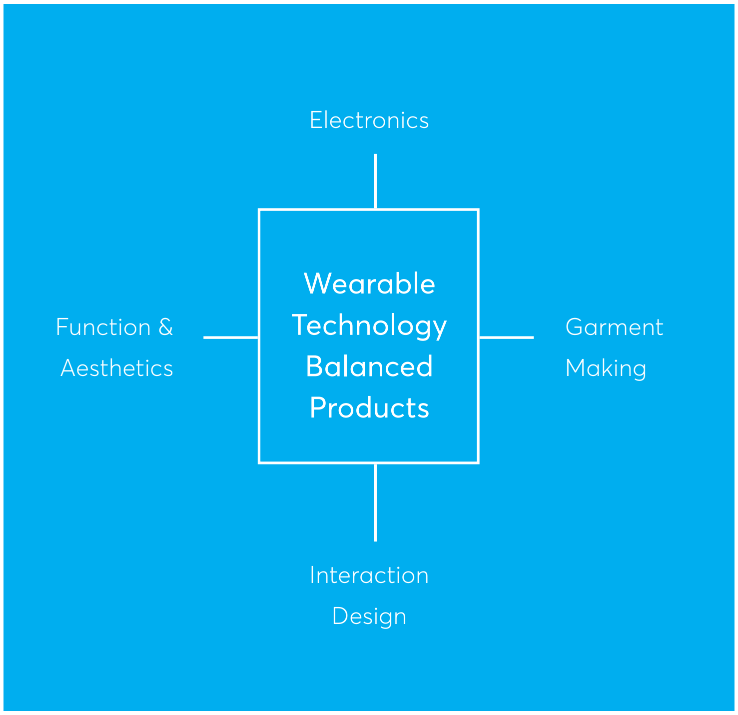


Figure 2.5.1
Parallel activities/multidisciplinary collaboration for smart clothing products

Therefore as a new industrial revolution takes place, with technical textiles and electronics industries merging, training and support is required in order to approach Textiles, Clothing & Fashion from a more product design user-driven perspective.

The ever-growing spectrum of smart textiles and wearable technologies has the potential to take the textile and fashion industry in a completely new & sustainable direction, far beyond its traditional roots. At the same time, fashion has the potential to leapfrog the gadget-focused consumer electronics industry and tap the growing wearables market with fashionable high-tech textiles (Parkes, 2015). From a company's side of view, those which succeed in merging these two different industry worlds can create very interesting, sophisticated and revolutionary products (Zimmermann, 2015). From the consumer's point, the integration of smart functionality into clothing and other textile products into the digital prototype is essential in order to alter our relationship with them and the way we use them.

QR Codes

1. 2. 3. 5. 6.

8. 9. 10. 11. 12.

13. 14. 15. 16. 17.

18. 19. 21. 22. 23.

24. 25.

3

Digital Prototype in a new Dimension

3 Digital Prototype in a new Dimension

Product Development is defined as the design and engineering of products that are serviceable for the target consumer, marketable, manufacturable, and profitable (Glock et al, 2005). More recently, for (Ulrich & Eppinger, 2015) product development is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a productive product development many tasks are unique, project requirements constantly change, and the output—thanks, in part, to the widespread use of advanced computer-aided design and simulation and the incorporation of software in physical products—is information, which can reside in multiple places at the same time (Thomke, 2012).

Fast Fashion has become faster and more furious. As fast fashion accelerates, shoppers require their needs to be met at the right price and on the right day (Cocozza, 2015). On the other hand, consumer is relenting in his demands and increasingly sophisticated; high quality, low prices and constant newness are what interest him today. The market is increasingly saturated and combined with the above, makes tried and true fashion strategies such as geographic expansion and internationalization more complex than in the past (Papahristou, 2016).

Digital prototype in the textile and clothing industry enables technologies in the process of product development where various operators are involved in the different stages, with various skills and competencies, and different necessity of formalising and defining in a deterministic way the result of their activities.

Taking into account the recent trends in the industry, the product development cycle and the use of new digital technologies cannot be restricted in the "typical cycle" but additional tools and skills are required to be integrated taking into account these developments (Papahristou & Bilalis 2015).

In this chapter the traditional garment sample development process is firstly outlined, followed by the problems the industry faces today with the change of business models. The approach to the problem along with the methodology of the research is being explained in section 3.3 and the in depth analysis of the two different processes: the 2D and the 3D. The chapter concludes trying to investigate the future of the physical sample regarding the virtual one and what remains to be seen on the 2D CAD systems in the fashion industry.

3.1 Traditional Garment Sample Development Process

Most manufacturers begin the design phase in the traditional manner with stylists' creative ideas originating essentially from a 3D shape (a 3D conceptual idea in mind or a completed garment already existing) from which 2D information are extracted, such as 2D sketches, 2D patterns with corresponding fabric layers (3D-to-2D stage). Some designers still use pen and paper as design tools but the introduction of powerful and relatively inexpensive computers, systems, and graphics software such as Photoshop, Illustrator, and CorelDraw has encouraged the textile and clothing industry to use this versatile medium to help create and develop their designs (technical illustrations and visuals), presentations and clothing ranges, and manage their workflow (Burke, 2015). Other companies have integrated powerful CAD apparel and textile suites in all the areas of the product development process from textile and fashion design, pattern making, grading, garment production through to merchandising, and data management. These solutions are expensive but apart from all the advantages that have been explained in sub-section 2.1, an added advantage is that the pro-mentioned economical graphic software such as the Adobe suite are compatible with these CAD apparel software tools. For example, features such as "drag-and-drop" can be used and/or files can be imported directly into these programs.

A fashion designer, a fashion design assistant, a pattern maker or a team prepares a technical pack (tech pack is its known), with specification sheets that contain an accurately drawn flat (line drawing of a design), and all relevant information (instructions and measurements) about how the body of the customer looks like. These tech packs are of most importance and form the basis of a binding contract between the brand/client and the factory/manufacturer that produces the garment.

This creative output then passes through the classical product development cycle, to sewing the prototypes to get a physical 3D garment shape as close as possible to the original stylist's idea (2D-to-3D stage), and after innumerable iterations finally reaches the production stage. Once the samples get to their destination, the product decision cycle begins in order to finalize the collection. Right at this stage the product coordination becomes an intercultural adventure: The more personalities involved, the more difficult it is to establish stringent and efficient communications. This is the case in particular when the fundamental for decision-making leave a lot of room for interpretation (Lanninger, 2013). This is a very expensive iterative process for the industry: for any accepted design, many more are discarded and will not go into production.

In the past, every brand would have designers creating styles and next door stitchers would produce the prototypes so that they could see the results straight away. The design studio was staffed with people with different areas of expertise and equipped with sewing machines operated by stitchers (Papahristou & Bilalis, 2016).

The research proposes that the traditional process of sample making has not changed. On the other hand, Lectra states that now the traditional product development process no longer works.

"Automating previously manual processes certainly has its advantages, but basic technology is just not enough to compete in today's market. Change and agility need to accompany new technology" (Lectra, 2014)

Heikki Haldre, Co-Founder of fits.me[26] addresses that the traditional prototype process certainly works. It is just as expensive as it was before. It certainly works, companies certainly use it however the newer systems could provide additional benefits, like making it faster and making it cheaper.

The problem though is that the old way of working is already set. Zara, one of the largest retailer, have already set a way of products to fit as fast as they have managed; new technology like 3D virtual prototyping or 3D visualisation was not available when that certain way was set. They have found how to create products without going into this technology. However, that doesn't mean that there aren't any benefits of it; with so many samples in the product development, the problem still exists in (Kochar, Appendix 1). It is just whether companies are serious enough to look into it or whether they want to concentrate currently on the retail side since all of the sudden there is so much technology that has been made available; then gradually shift towards the other end. As most of the participants in the research pointed, the change is happening yes but it's happening slowly.

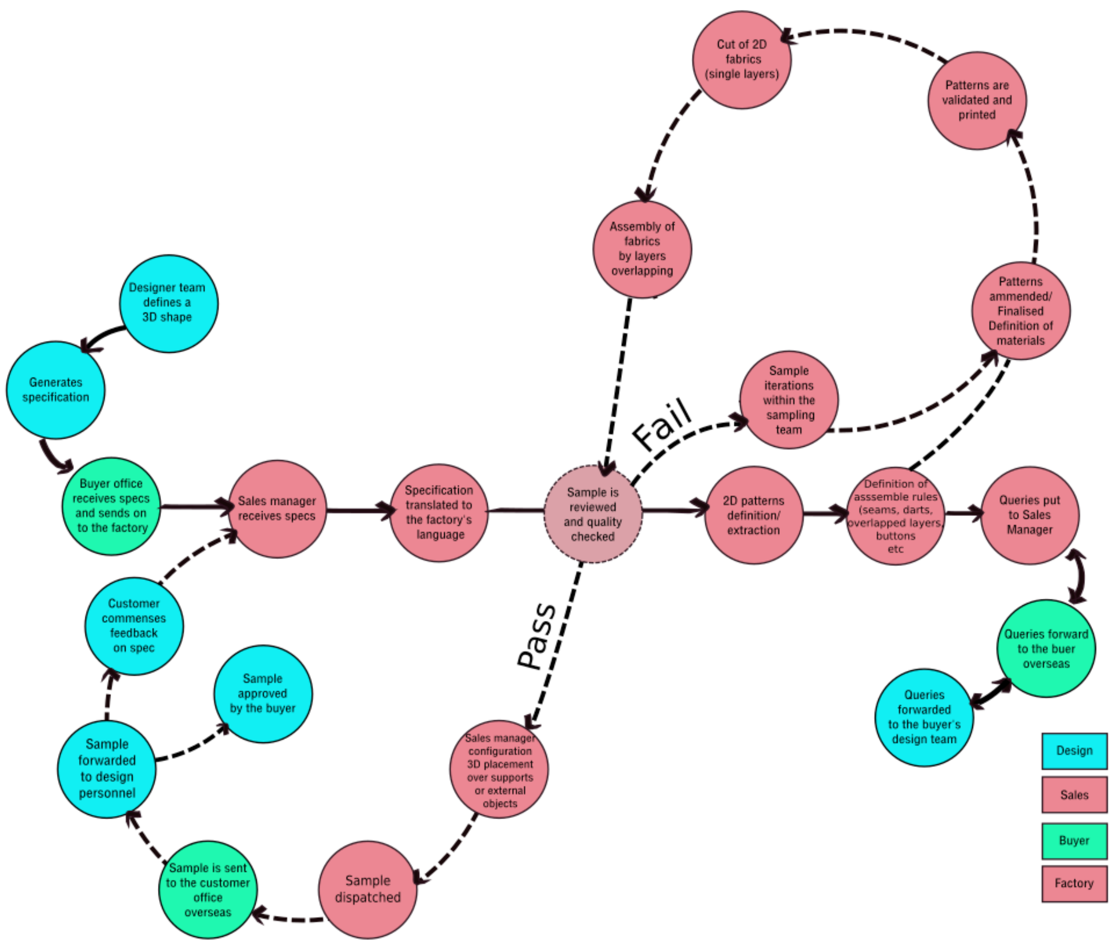
3.2 Problems facing today

As it has been several times noted, fashion is a very traditional industry—unlike other industries. But not all tradition needs preserving—especially not the currently chaotic manufacturing system which involves a lot of time, money, and guesswork. In this section we will try to summarise the major problems that academic research have identified and compare them to what the people from the industry who were interviewed have pin-pointed. According to (Dhapokhar, 2012), the biggest problem in the garment industry today is (a) the time spent in developing and approving samples. In India he notes, it takes anywhere between 40 to 50 days for a style sample to be accepted. The typical production process requires designers to attach 2D drawings to an assortment of attachments and glued fabrics, followed by multiple shipping rounds to subcontractors in third countries (Elias, 2015). Design development may require six or more iterations being sent back and forth.

[26] fits.me is a web platform with software solutions that enable retailers and brands to understand their customers in terms of fit and preference.

High sample numbers, and lengthy lead times, link directly to the accuracy of product specification, which might extend from a single illustration to many pages 9 (Fig. 3.2) (Papahristou, 2016). (McCann, 2012), agrees that approved samples are delayed due to (b) the lack of standardisation of software solutions, and the detachment of the designer from production processes, along with the above poor specification, which lead to queries sent back through the chain to the designer with substantial waste generated through inadequate interpretations of the design. Another study adds to that problem, reporting that the primary drawback of the most of the existing commercial CAD systems in the last decade, was, that they relied on mere geometrical modelling and did not provide virtual simulation tools (with few exceptions) (Fontana, 2005).

Figure 3.2
The garment sample development process



Three-dimensional (3D) technology—while well established in many other industrial sectors like aerospace, architecture and industrial design—is still relatively new to the fashion industry. 3D technology started to get in that market but needed technology advancements to get there (Elias, 2015).

It is not that the technology is not mature yet. (Walter et al., 2009) recognises that the apparel sector as a whole is lagging behind in its (c) willingness to adopt new technology to aid the product develop process, despite there being many innovative products on the market.

In hyper-competitive markets, technological innovation is essential for companies to grow. While the rise of technology is unavoidable, the fashion world is, for the most part, ignoring it and is looking at technologies that have been present in other sectors for over 10 years (Lectra, 2014). This can be explained historically because of the relationship with the product and also because no two fashion companies operate in the same way. Others say that the fashion industry fetishises technology as if it were a seasonal trend, not an ongoing revolution. Technology is changing everything, from product development to manufacturing to logistics to human resources to sales. Still, most fashion companies relegate technology to a subset of their marketing and sales departments, treating it as a side-project rather than integrating technology into core business thinking. A majority of fashion and apparel companies wait to see how it works out for others before changing their way of working (Lectra, 2014). It's time that fashion companies change their ways and follow vital digital transformations to embrace the tech revolution already happening in other industries (Court, 2015). This is the only way that the industry will overcome the problem of (d) communication between factories which is often difficult, delayed, and problematic.

The last but not least, major problem is (e) to achieve fit (Dhapokhar, 2012). Without fit garment has no commercial value. Once the style is received from the buyer, samples are sewn, shipped overseas, and a fit session is arranged with a live model that the manufacturer rarely sees.

Inaccurate fit forms and lack of communication cause a lengthy approval process. Very rarely, the first sample is selected as the final sample.

Participants in the research discussed all the above mentioned problems. However, they have given another perspective. As to the problem of the immature software solutions (b), the Digital Creation Leader of a Leading Sportswear Company, comments that even if you have the software, it is not enough. You have to think what is your process, what are the requirements for manufacturers when they submits models, how to communicate (d). Big corporations who have started to work on finding digital standards very early on, have learnt they need to build a complete new process plus a complete language in their creation process-design, product management, development and manufacturers need to be inforced as well.

3.3 Approach to the problem (methodology)

This study has been motivated by two major factors. First, the predictions that the fashion and apparel industry is going to change in the next ten years as it has over the last 100. Technology is revolutionary and overturning traditional processes. New software tools are equipped with 3D visualisation capabilities, and promise an enabled more creative, innovation-based workflow. Digital prototype is at the core of this change due to being part of the speed-to market pressure in fashion companies. However, it has been shown that even if technology solutions like 3D and virtual prototype has been around for some time, and has been named disruptive, the industry has been slow on the uptake. Therefore, disruptive might not be the right word but lately embraced and much more embedded in the fashion industry.

The second motivating factor for this study is that in general there has been a lack of research in the new dimensioned digital prototype of clothing at the product development level in a qualitative manner and from a perspective not so engineered-focused.

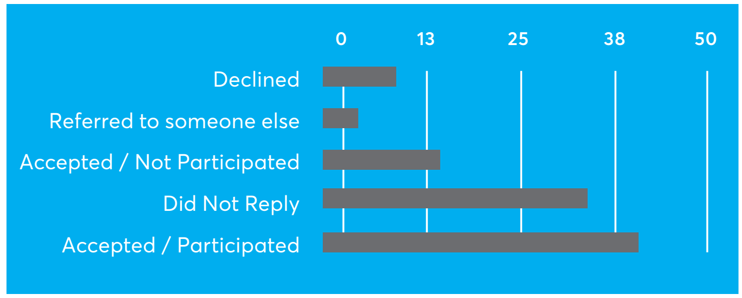
The research project gathered the opinions and experiences of experts with direct contact and use of the technology; the selection of the sample was purposive rather than random. Experts from four different backgrounds of the fashion industry were selected to participate in this survey contacting personal interviews. The first background was the vendor side; executives from companies who have been offering technology solutions to the industry for many years but also start-ups who have been very successful by entering the global technology impact game with exciting and promising tools. The second background was the industry side. We approached people working in the industry for years, trying to implement these accelerating technologies into the product development process. While we were trying to involve and interview users of the digital creation tools in the survey what it intrigued us was the fact that the approach to the implementation and adaptation of the technology of the executives in a managerial level was quite different to the level of the technical person/designer/pattern maker/3D user. Therefore, the survey decided to include both parties (managers and users) adding up freelancers and independent experts as well in the process. Since education places an important part in the adaptation and implementation of new technologies in industries we included academics with significant research work and contribution in the field.

The next step was to form a semi-structured questionnaire with the topics of interest. The kind of questions asked followed (Kvale's, 1996) nine types of qualitative interview questions:

1. **Introducing questions**
2. **Follow-up questions**
3. **Probing questions**
4. **Specifying questions**
5. **Direct questions**
6. **Indirect questions**
7. **Structuring questions**
8. **Silence**
9. **Interpreting questions**

In total, 100 experts were invited to participate in the qualitative survey. As Fig.3.3a shows 43 "relatively unstructured" personal interviews were carried out; some of them in typing due to lack of time on their behalf or the time difference between countries. 34 didn't respond at all, although they have been contacted with a coming-up e-mail twice.

Figure 3.3a



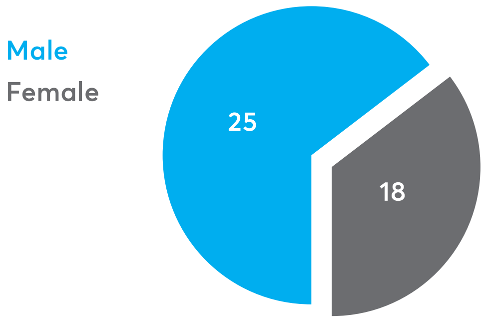


Figure 3.3b

14 responded positively, accepted the invitation but the interview never happened; they have probably neglected it. 2 responded positively but referred to other experts instead due to insufficient knowledge of the discussed subject and 7 declined the interview based on the lack of free time on their behalf.

Below in the Figs. 3.3b, 3.3c, 3.3.d & 3.3.e participants are categorised in some demographics; Gender, Age Group, Country of work and Occupation.

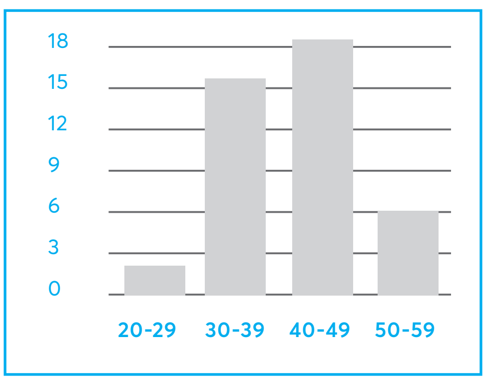


Figure 3.3c

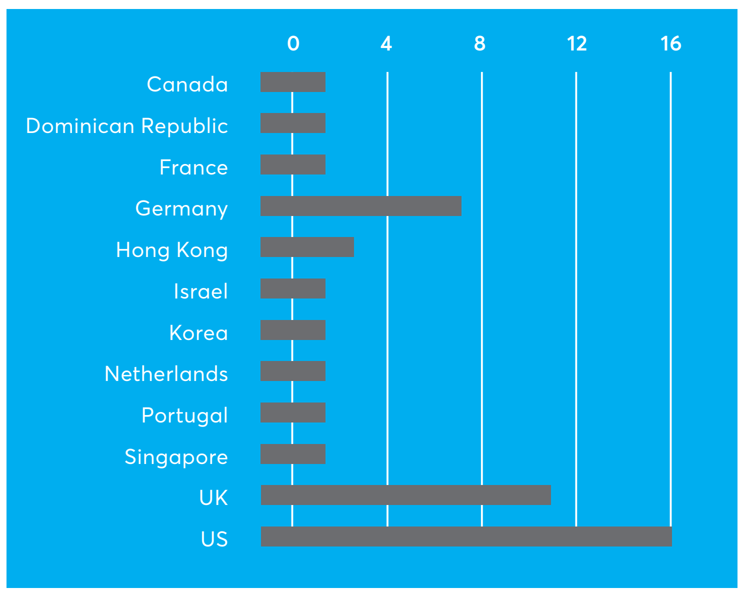


Figure 3.3d

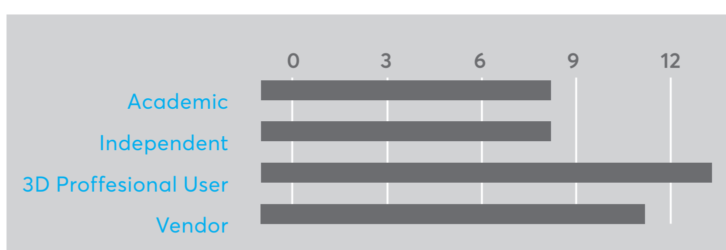


Figure 3.3e

Figure 3.3a
Attribute-Response
Figure 3.3b
Attribute-Gender
Figure 3.3c
Attribute-Age Group
Figure 3.3d
Attribute-Country of Work
Figure 3.3e
Attribute-Occupation

There are some points that need to be noted: The context of the questionnaire was changed in the process as interviews started to evolve. The interaction with the participants raised more and different issues than the ones that the survey initially started with. The open-ended, discursive nature of the interviews permitted an iterative process of refinement, whereby lines of thought identified by earlier interviewees were taken up and presented to later interviewees.

The way of interviewing had the following aesthetic:

- The approach was structured to maximise the reliability and validity of measurement of key concepts
- The order of questions varied and even the wording. New questions were asked following up interviewees' replies
- It was conducted in a flexible way responding to the direction in which interviewees took the conversation
- In some cases, interviewees were interviewed more than once

Other challenges that needed to be handled were Dealing with our Data (how to make sense of the data collected) and the Time element of the research project. Over a long time span, human memory becomes fallible. As the research and the interviews proceeded over the months, it was obvious that a digital archival or research information and resources was needed. The collection of primary data was not only relied on personal interviews but on surveys, notes, fieldwork and a combination of information types. These qualitative research methods require transparency to ensure the 'trustworthiness' of the data analysis. The intricate processes of organising, coding and analysing the data are often rendered invisible in the presentation of the research findings, which requires a 'leap of faith' for the reader. Computer assisted data analysis software can be used to make the research process more transparent, without sacrificing rich, interpretive analysis by the researcher (Ryan, 2009). Therefore, the software NVivo was chosen as a state-of-the-art analysis tool for qualitative and mixed methods research.

In order to put Internal Data like interviews in the NVivo software, the data has to be transcribed in word text document form.

Before entering the transcribed interviews in NVivo, transcripts were thoroughly read and nodes were created in the process to house relevant excerpts or text from the transcripts; we looked at the research questions, we chose some overarching nodes which would enable us to draw out sections of data analysis and the process of devising coding categories or nodes begun. The software enables the researcher to develop tree nodes which show relationships between and within nodes, and consequently between and within data sets. It must be noted that software programs such as NVivo do not do the intellectual work for the researcher, nor do they assume context free analysis; rather they facilitate creative management of multiple data sources and enable researchers to make visible their methodological processes for a more 'trustworthy' study (Ryan, 2009).

The content of this research with the Chapters, and sections of this research came out from the tree node NVivo development.

3.4 Main differences between 2D and 3D processes

In section 3.1 we have described the traditional process of working in 2D environment. In summary, a customer gives to the factory a tech pack with information for what the product is going to look like, what the measurements are supposed to be and the pattern maker/operator creates a 2D pattern to fit to your target customer, cuts it in fabric, sews it, tries it on, sends it back to the customer, makes corrections then return it, make other iterations and then again do the fitting on a real model until the final sample is approved. With this process the visualisation part of a finished garment, in the initial stages of the process, is missing and only great pattern makers can look at a 2D pattern and guess what it will do on the form. Usually, a physical sample is needed.

Image 3.4a

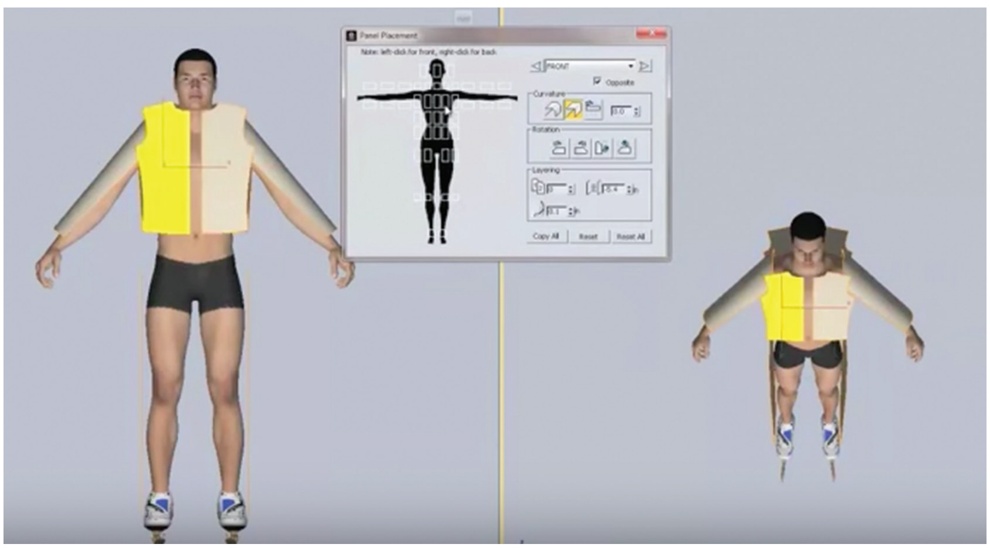


Image 3.4b

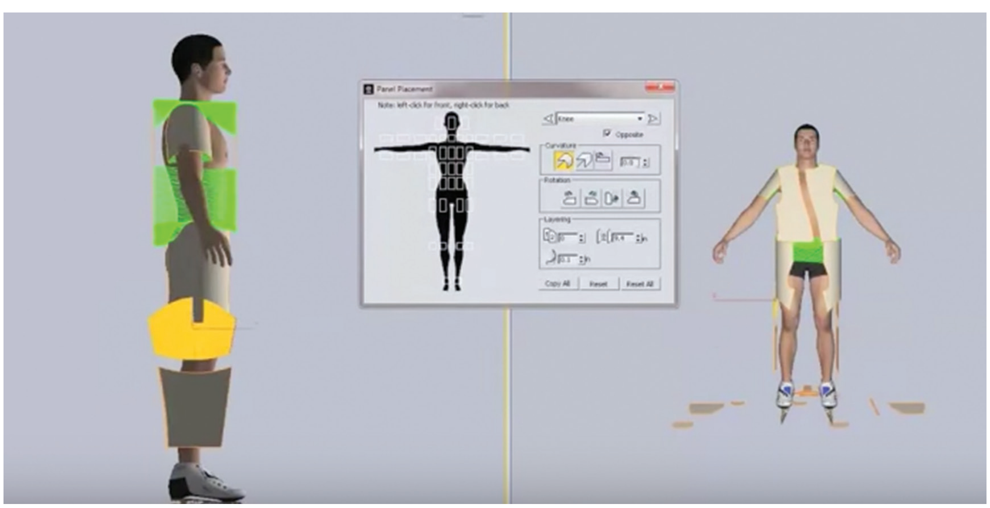


Image 3.4c

Image 3.4a
Virtual stitching of the 2D patterns *(Source: Tukatech)*

Image 3.4b
Placing the patterns around the avatar (1) *(Source: Tukatech)*

Figure 3.4c
Placing the patterns around the avatar (2) *(Source: Tukatech)*

Image 3.4d
Virtual fitting of pattern pieces of the same fabric *(Source: Tukatech)*

Image 3.4e
Adding the rest of the fabric pieces and visualisation through movement *(Source: Tukatech)*

Image 3.4f
3D visualisation of final product with fabrics, trimmings & graphics *(Source: Tukatech)*

Figure 3.4d

With the 3D process, the steps until the 2D pattern are the same.

"The file with the 2D pattern is sent to the 3D operator, opened in the 3D software tool, select the fabric properties, place the pieces around the body, electronicaly stitch the pieces together, drape the garment, add animation. After the fit is approved, the 3D operator is free to add different colours, graphics, trims, etc to render movies and image files" (Crawford, Appendix 1)

See Images 3.4a, 3.4b, 3.4c, 3.4d, 3.4e, 3.4f.

Image 3.4e

Image 3.4f

In this question, interview participants identified that 2D process:

a. Is a long and almost obsolete process
b. Lacks visualisation ability of a finished product which only a physical sample can provide
c. Is more modular based, since designers have been working that way for long; they have all the basics they need to provide a design and make changes
d. Has a benefit of being an established process and each function (be it design, development etc) can work independently
e. Is a stand alone tool; can work without 3D
f. When integrated with 3D, allows simultaneously changes from 2D to 3D in real-time
g. Requires traditional skills like all the manual methods

All agreed that the above process is very different to the one of 3D. More specifically, 3D process:

a. Is a shorter process and capable to show a lot of flaws of the 2D process. However since it has just started to be implemented, it takes longer but as anything else, the more you use, the faster you are; commented a UX/3D Apparel expert in an 3D early adopter company.
b. Adds a step of visualisation. Designers can have better understanding of patterns and various behaviours of drape with various division lines; a more accurate representation of shape and fit which can be changed more easily
c. It is not the primary mode of design for fashion companies. It is being used most productively for simple garments (sports etc), but increasing in other areas. i.e Target Corp has a dedicated 3D group (Bruner, 2016, Appendix 1)
d. It is not a stand alone tool; cannot work without 2D and always requires a 2D pattern
e. Creates dependencies and needs new processes which are partly yet to be established (Sluiter, 2015, Appendix 1)
f. Makes the importance of design-pattern collaboration more evident

g. Allows simultaneously changes from 3D to 2D in real-time
h. It can be used from designers who do not have pattern making experience to make and visualise change
i. Requires an understanding of the construction of the garment as with 2D, but also technical computer skills
j. Requires a virtual library of material and textures; photo-realistic images of fabrics with specular maps. The only way to have those images is via a flat-bed scanner

The following Table 3.4, summarises the most commented differences:

Table 3.4: Differences between 2D & 3D processes

	2D	3D
Established thinking	✓	–
Visualisation of finished product	–	✓
Photorealistic images with specular maps of texture	–	✓
Stand alone tool	✓	–
Simultaneous changes from 2D to 3D and vice versa	✓	✓
Traditional skills	✓	–
No need of proficiency in garment making	–	✓
It is a long process	depends on the user	depends on the user

3.4.1 How the traditional method of garment prototype has been altered with 3D virtual technology

In this question there were several answers. Trying to categorise the answers we decided to divide them based on the relationship that the participant had with the 3D virtual technology at the time of the interview i.e vendor, 3D expert in an apparel company, independent 3D expert and academics. Later, we will try to find some similarities in the responses and draw some outcomes.

Vendors of 3D technology

The changes made in the product development process would depend on the clients' needs and the main user of 3D solution in the company.

Director of R&D of Clo Virtual Fashion Inc, Yongioon Lee (Lee, Appendix 1), reports:

" If A client (Brand/ODM) would like to use CLO software at the early stage of their product development cycle, designers would substitute 2D sketches to 3D virtual designing. Client's main focus is on enhancing designer's creativity and making quicker decisions. If B client (OEM) already has the patterns ready, and would like to use CLO software to check the balance of the garment; he/she would substitute several real samples to 3D virtual samples to check the balance and errors of the patterns. Client's main focus is on reducing lead times & cost, and improved communication with buyers (also between designers and modelist)"

The WorldWide Managing Director of another vendor company opposed to the previous account, states that with the use of 3D the designs/sketches still need to be made in 2D. It is the 2D pattern that is virtualised in a 3D prototype and all the iterations are made on the virtual prototype instead on the physical sample. With the 3D process changes can go back in the design phase and modifications on length, seams, cuts, colours, prints and so on can be made. This is the difference; it reduces iterations. Only when the virtual prototype is approved then the physical one is produced and most of the time 1 or 2 physical are produced and then the final design of the garment goes into production.

Sharon Lim, Managing Director of Browzwear, pinpoints that

"the most difficult part in product development is taking a decision (of what we don't see). 3D is definitely a solution enabling making it (the decision) faster. Visualization is what makes the decision taken faster. The minute you can take a decision, the minute you can move on" (Lim, 2015, Appendix 1)

According to her, the physical process of cutting hasn't really changed. It has been enhanced with 3D. If 3D is used in the concept creation phase then the product development stage will increase significantly.

Analysing the responses of the vendors in this question we understand that the product development process has not changed with the use of 3D. As the Chief Collaborator of Tukatech notes,

"The idea (at least behind Tukatech systems—I can't speak for others) is to mimic whatever a pattern maker or sample maker would do in real life, but to do it more efficiently on a computer" (Crawford, Appendix 1)

3D Experts in apparel companies

The answers to the question "how has the use of the virtual prototype technology changed the way you and you team work?" were again different due to the fact, as it was mentioned in sectiov 3.3, that operations in companies differ.

Big corporations like Nike and Adidas who have started to include the 3D prototyping tools into their development processes almost a decade ago, have a lot of experience, have gone through many phases, many pilots, have employed many people as 3D users and they believe they have a clear view of what is working with 3D and what is not. The virtual process to them began in their factories in Asia, following the physical production which took place there. Those factories are doing much of the virtual modelling (the 3D creation of a sample); the process starts after the physical sample is created. For them, the sample reduction did not pin out the way it was hoped originally. The old process is currently active. Designers make sketches in Illustrator, they send the files with an XLS file (tech pack) to the factories.

It is predicted that 3D tools like Lotta (Browzwear) will integrate with Illustrator, capture all the designer's information (fabric, trimming, annotation) and can be opened in a 3D prototyping tool like V-Stitcher by the factory. Factories in Asia are obligated to use the same 3D prototyping tool as the company in Europe or US but they are free to select their own CAD system.

Detlef Muller, Director of Creation Digital in ADIDAS, argues that they do many pilots but they keep in a small scale which means they have to keep the existing process. In order to get all the benefits of the 3D advantages, ideally, they would skip the existing process. They cannot do that because designers are working on different products and on different working modes (2D & 3D). They concluded that this is not working. They need to find a way,

"to take out a team of a few people, create a pilot, all working in the same way, don't give them any process restrictions, of course there are deadlines they would have to keep, but all the rest would be totally free" (Müller, Appendix 1)

Dominic Sluiter, 3D Lead at NIKE Global Football Apparel says:

"We do different things. We use 3D tools to communicate with the factories. And that can be in different stages of the process. That's a communication tool between factories, development, design and before we see a physical but it can be after that. After we see a physical we might also ask for a 3D for a presentation. So, we do a mix. We use it before we see a physical but also after" (Sluiter, Appendix 1)

In order to decide how to include 3D prototyping in the process, big companies look at the project and try to find out what they are looking to get from doing the project in 3D. Designers get recommendations; some begin to build preferences in applications, others switch back and forth. Even big corporations with several years in experimenting with 3D have just started to understand the acceptance of these tools and how much work there is ahead of them.

They tried to build a powerful team of designers with a strong User Experience in 3D and then it's up to designers to choose which process to use in their work projects. It started as a good foundation with their manufacturers, building a process with their developers, they eventually created a pool of other functions as well and next to a developing tool, 3D became a presentation tool and the goal is to make it a design end-to-end tool; from the

"creative process steam all the way up to commercialisation and even sales, ideally" (Sluiter, Appendix 1)

"You can then share 3D images to even consumers or a group of consumers and get feedback. That means that the designers interact not only in their own little bubble, let's say it like that, they could interact with consumers at the end and ask for feedback. We have done some trials with that and that's good" (Müller, Appendix 1)

Margarita Pasarkamis, 3D Patternmaker, responsible for implementation of 3D technology in VF Jeanswear Product Development Process, agrees with the vendors' point of view that 3D has enhanced the traditional process. It certainly has changed the way they work. It depends on how the tool is used. It can skip a few fitting processes for a sample, it can be part of virtual presentation or it can be a combination of both.

"3D saved a lot of time, gave us more options. If the user is really good, can do 20 versions of a virtual product in a single day without cutting it or sewing it" (Pasarkanis, 2015, Appendix 1)

3D Experts in the clothing Industry / Independents

What is interesting in this group of participants is that although they agree with the statements and vision of the software vendor companies that 3D virtual prototyping changes the lead time on a garment, helps to make developing the garment easier and helps to communicate final product visually to buyers, managers and everyone involved in the process. They involve some restrictions in order to achieve all the above. For companies which want to reduce the number of samples yes it could be done before the final approved development sample; only if the company has truly embraced 3D.

"It would depend on the existing process within a company when it is going to alter for sure. How many staff can they allocate to 3D—that's why many companies are choosing to use it selectively" (Bell, Appendix 1)

Joshua Young, Digital Product Creation Consultant, with many years of experience in a large sportswear company believes that big companies who adopt 3D in their processes do not want to shorten their timeline; on the contrary they want to give more time to designers. Digital prototypes for those companies are used to get better prototypes sooner so that the end product is better. They want to reduce the amount of work load that the team has so they can concentrate on the truly innovative styles (Young, Appendix 1).

It seems at first that there are many different perceptions on the way the 3D prototyping technologies have changed (and to what extend) the traditional development process. However, the most interesting issue that came out of the discussions is that the industry (apart form being very slow in changing traditional methods) and especially those companies who have embraced 3D virtual as part of their development cycle is that they experimented first with this technology starting from the development of the final garment trying to reduce samples. In the process, they piloted in the early stage of the concepts' design and presentation in order to enhance the creation phase.

In the Fig. 3.4.1 we present the two engagements of the 3D technology in the product development process.

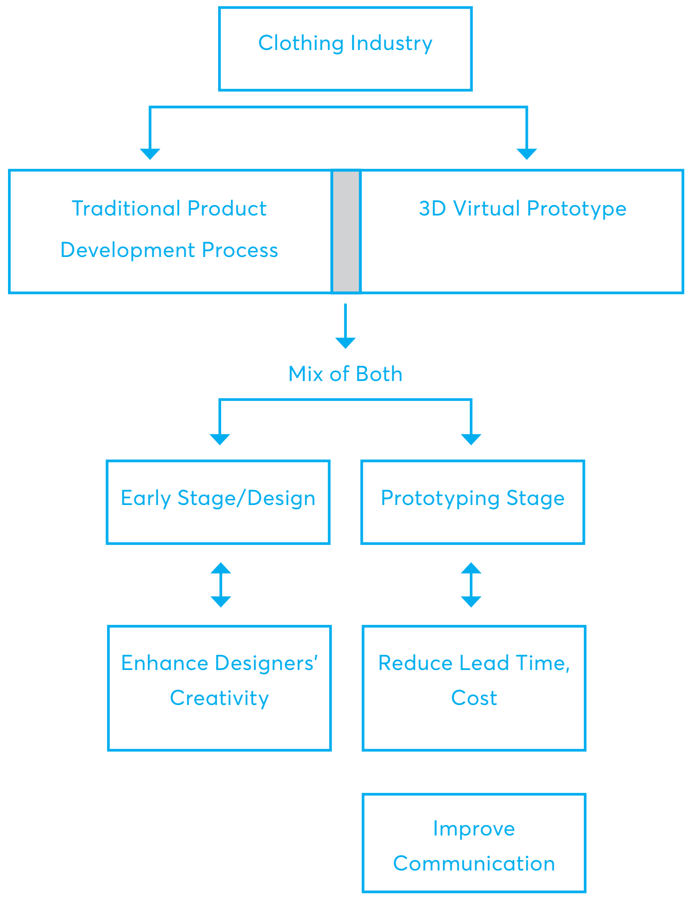


Figure 3.4.1
Engagement os 3D virtual prototyping technology in the traditional product development process

It becomes apparent that 3D Visualization and 3D prototyping tool needs to be defined, therefore, we will try to investigate in the following section, 3.4.2 the differences of the two applications of 3D virtual technology; as a 3D visualisation tool and as a 3D prototyping tool.

3.4.2
3D visualisation & 3D prototyping and virtual fitting

The following Figure was drawn from the answers of the participants with the goal to explain the thin line that exists between the two areas of application of 3D virtual technology in the apparel product development. As the CEO of Optitex, Asaf Landau put it,

"The creation of 3D and the use of 3D".

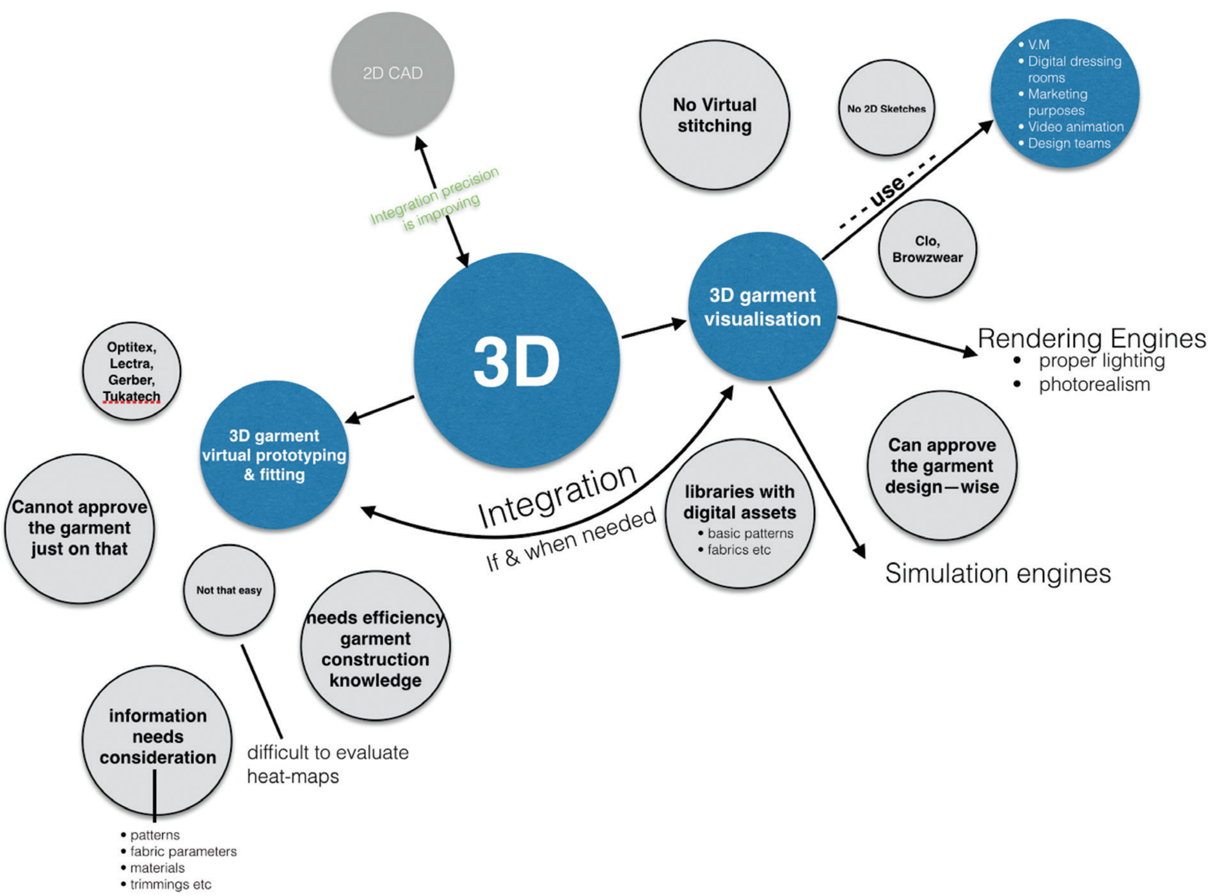


Figure 3.4.2
3D technology split in two—
the creation and the use

3.5 Is the future of physical sample of garment unstable?

In the question if the research participants can imagine the fashion industry without a physical sample, all replied NO. In the previous sections of this chapter we analysed the areas of applications of the 3D virtual technologies in the fashion and apparel industry. It was pointed that 3D technology did have the goal to reduce physical samples of the process. However before we continue in reporting the outcomes of this query, it is important to draw a distinction between prototypes and samples.

Prototype is what it is made while trying to perfect the product, so when a tech pack is sent out to a factory and a prototype is sent back, before it's finished as the process is still on-going, prototypes are created. Once it is finished and a physical sample is ready for the sales team or the retail then the prototype becomes a sample. A sample is what you get after you have finished working on the garment—the sample of the garment. This is the reason why the digital prototype needs rendering—because it is not necessarily a nice visual yet.

It seems that 3D virtual samples can not replace all physical samples at the moment. Vendors use the advantage of sample reduction of 3D but they don't believe that virtual technology can eliminate all the physical samples. In particular,

"Fashion industry would need at least one pre-production physical sample to check the fit of the garment. We recommend users to rather focus on its efficiency in quicker decision, e-commerce, enhanced communication and creativity" (Lee, Appendix 1).

Mark Harrop, CEO of WhichPLM says that

"…whether we like it or not we still require that physical sample I believe" (Harrop, Appendix 1).

See Fig. 3.5

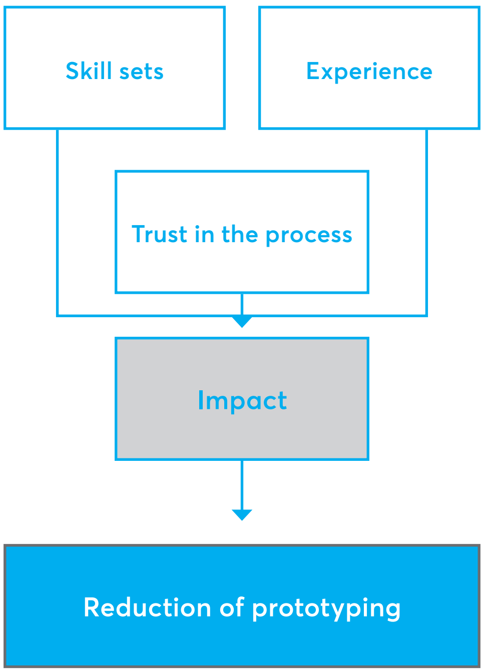


Figure 3.5
Parameters that impact the reduction of prototyping
Source: Gill, Appendix 1

Below are some issues that make the requirement of a physical prototype necessary:

- Materials substrates that react differently and stretch differently
- Most of the brands in the world do not own the manufacturing base; therefore a shield sample is needed for a reference
- Cross-functional environment with a change of mind in design and feel of the garment
- Not everyone is on board with the technology
- Valuable feedback for and on decision making
- Check of physical construction and fitting

3.5.1 Physical vs Digital

Digital Prototypes are used as an essential tool in the modern design process. The integration can speed up the design process and affect competition between companies. However, this technology will not replace the aesthetic appeal of great products, the magnetic attraction of great brands, or the advantages of extended portfolio assets, because the fashion industry will continue to build great products, brands and businesses as it has done successfully in the past. But technology will, indeed, replace products, brands and financial strategies as the key source of value creation (Beltramini, 2014).

In the high-fashion/luxury sector, where digital prints are applied on a large scale and on expensive fabrics, physical prototypes are restricted. Brands like Roberto Cavalli, would go ahead using hand-made crafting techniques, making paper dolls to which they apply the fabric image, using pins or cellotape, in such a way as to have an idea of what the correct, print position would be on their model. (see Images 3.5.1a & 3.5.1b)

Image 3.5.1a
Roberto Cavalli paper samples
Source: roberto cavalli

Image 3.5.1b
Roberto Cavalli paper paper dolls with print image
Source: roberto cavalli

Making physical samples can cost a clothing company several thousands of dollars per sample and can take several weeks to produce. Coach produces 28,000 physical samples (costing millions for the business), before factoring in the need for changes in shape or colour-ways. With the new 3D solution they are able to develop an extra 10,000 design options per season, helping to provide an extra 40,000 options for the business. (Hanson, 2015).

Some vendors even talk about cutting the overall product development time by 30–50% (Optitex, 2015). Indeed companies like F&F[27] after implementing 3D virtual prototyping technology in the design development process, have reduced the number of samples made for each product to 1,2 comparing to 1,8 18 months ago (Thomson, 2015). Target's goal is to reduce samples by 65% (Gagnon, 2015). Gerber argues that after the adaptation of 3D their clients would do all the iterations using 3D and create only one physical sample.

Two very experienced users of the 3D technology in apparel and footwear, one 3D V-Stitcher Pattern Maker in VF (Jeanswear) and the other 3D Senior Designer in Adidas, claim that the benefit of virtual process is not reducing samples but instead on adding on a lot more samples.

"It is not about the quantity—it is about the quality. We have more turnover from this product development process, more cycles in the same period of time, the quality of the product is better" (Pasarkanis, Appendix 1)

"3D has the potential to reduce physical prototypes but it is not the only benefit. At Adidas physical protos have been reduced by the use of 3D in the past already, and I see some further potential in this area for the future" adds Schirin Negahbani, Product Manager and 3D support for Users (Negahbani, Appendix 1)

It is known that many retailers / brands are still producing tens, hundreds sometime thousands of physical samples. A 3D garment developer have experienced that process could end up to 20 samples to get that approved one. Making physical samples is certainly cost-effective.

[27] Clothing branch of UK supermarket chain Tesco

For most manufacturers though, 3 at least samples are necessary; the best one is being sent to the retailer, one is kept for the library and one for themselves. (Harris, 2016), (Trautman, Appendix 1). With fast fashion companies signing agreements to turn products in 6 weeks, 5–6 samples are going back and forth between countries before the final gets approved.

Companies who have embraced the technology early-on didn't reply to the question of how many physical samples they are doing after 3D in their processes. Instead they replied with the number of virtual ones.

Digital Pros

- A very good one works for visualisation purposes among the sale teams.
- More virtuals now than before.
- The cost of one physical was reduced by 50–75%.

Digital Cons

- Not enough trust with fit yet.
- Designers & creatives are not very confident in believing the virtual fit.
- Fine details, fill of the fabric, the way two different fabrics are constructed together are still evolving in the virtual world.
- How the garment product fits is everything about a company.

Potential of Digital sample

- A really good 3D system would eliminate the need to physically sample each of the size (size ranges) of a product.
- If the technology can get the industry to produce 1 or 2 samples the saving in terms of cost would be tremendous.

"The value in getting the product to market faster in lower cost of samples and the environment just to name 3 effects are immense" (Harrop, Appendix 1)

- Having a physical sample may not be a priority although it will still exist.
- It is too easy to say it will reduce samples—definitely in the long run it will get there.

3.5.2 2D CAD Systems: Game Over?

As it was shown in Fig 3.4.2 in the section 3.4.2, the 3D technology based on its use, has two approaches.

1. Virtual Prototyping & Fitting and
2. 3D Visualisation of the design

Based on the responses, the 1st, is consisted 80% of 2D and 20% of 3D. The developer cannot be successful in 3D without a strong background and understanding of dimension, CAD software, pattern making and construction of the garment, because "in the end that is exactly what it is" (Alamachere, Appendix 1). For participants who are in the group of 3D UX experts, their opinion is that in order to be in a place to prepare a 3D workflow, 2D understanding of its aspect is needed. In Section 4.6.1 the needed skills of the 3D user are thoroughly examined but basic understanding and foundation in pattern making is a key to success; otherwise it can be an obstacle. Does that answer the question? Maybe no. It shows however, the need for technical skills which CAD Systems demand also. Mark Harrop, a futurist as he calls himself, with more than 3 decades of experience in manufacturing, production & factory management, in 2D & 3D CAD, PDM, PLM, ERP etc, made a prediction that

"in 5 years from now we won't have 2D pattern systems. Lectra Modaris, Gerber Accumark will eventually die, in the sense that we' will start from 3D like engineering aerospace and others do, and we will move out of flat patterns" (Harrop, Appendix 1)

For the 2nd approach, can we imagine an apparel designer without working in Illustrator doing 2D sketches? 3D visualisation tools like Lotta, and Tuka3D and Tukadesign are already integrated with third party graphic design software (i.e Adobe Photoshop, Adobe Illustrator) which are platforms for young/amateur users. How can these 2D files been replaced?

CAD is the basis of a garment. Some industry experts believe that today's CAD technology should have been changed but it hasn't. Collaboration is a key word in technology.

"Imagine a world where all of this is available to anyone. It's not that they are not there. It's there. It's just that they are not shared. Today everyone is collaborating. So, why not patterns? The future of smart patterns is really about collaboration & more portable patterns" (Lim, Appendix 1)

The world of CAD is not over. It has to rethink. In the future we will grade in 3D instead of grading in a flat pattern. New CAD starting with holograms with measurements input which link to the profile and avatar of the customer, from almost self design, to self posture, to cutter manufacture will replace today's CAD solutions for the fashion industry.

4

Virtualization as an Integral Part of the Fashion Product Development

4 Virtualization as an Integral Part of the Fashion Product Development

The 3D concept is a serious development in the design process. It allows designers to unleash their creativity in a real-life visualization of designs that could previously only be imagined through 2D sketches. It is clearly visible that the world is going digital. 3D Virtualisation plays a leading part in this. According to Dassault Systemes though, many processes still do not live up to their full potential. Creative 3D materials has always been painful where as vendor software companies claim that with 3D virtualisation is a fantastic way of starting the process of apparel product development. If it is so, then why is the industry using 2D tools to design products that are fundamentally 3D objects? If 3D virtualization has so many benefits and potential for the business why hasn't it been adopted in a large scale yet?

The primary drawback of the most of the existing commercial CAD systems in the last decade, was, that they relied on mere geometrical modelling and did not provide virtual simulation tools (with few exceptions) (Fontana, 2005). 3D technology started to get in that market but needed technology advancements to get there (Elias, 2014). The first developed sewing and draping tools gave the designers the ability to evaluate their design on the screen but the proposed approaches (McCann, 2012), were generally computationally intensive. Later, Wang et al. (Wang, 2003) developed a 3D sketch input method for the design of the garment pattern to fit the 3D human model but still, they were not effective in supporting design modifications.

Updated algorithms (Lu, 2005) provided 3D garment fitting simulation the ability to react to the 2D pattern modification efficiently and speedily without the need to repeat the entire simulation for every modification. Others (Jin, 2009), used parametric curves to control the silhouette of garment's shape more easily. Lately, (Meng et al, 2012) tried to solve the problem to generate customized apparel products for individuals with variant body shapes with a flexible shape control technique.

Three-dimensional (3D) technology—while well established and a powerful tool in many other industrial sectors like aerospace, architecture and industrial design—is still relatively new to the fashion industry which has started to adopt it in order to optimize the design and fabrication processes (Papahristou & Bilalis, 2016). In particular, the area we are focused on, design and product development, will make use of 3D tools that allow for garments to be created in 3D and converted automatically to 2D for traditional manufacturing methods. Digital body models can be created by 3D body-scanning systems, which will allow the digital products to be draped over them. The simulation of these digital products on the body can be obtained from the fibre and fabric characteristics. These data can be shared digitally and monitored through the product development process without the need for the development of a physical fabric or garment sample. (Nayak, 2015).

Gerber states that 3D design and visualization features, integrated into every aspect of the apparel process, from design, pattern making, production, and manufacturing, is now an important part of the revolution in digital design and production technology for apparel manufacturers (Gerber, 2016). New software development like Lotta (Browzwear, 2014) and YDT (Yin Group, 2014) provide direct 3D apparel design on the 3D human model to simulate the effect of the apparel on the human body;

it also, as argued in the previous chapter, allows design change under the 3D environment to avoid repetitive fitting by the real model in the traditional apparel design process and the repetitive manual changes. The fact is that 3D visualisation is now much more embraced and embedded in the fashion industry than in the past.

Interviewees were called to share their experiences, answer questions, examine & criticise the existing tools and help the investigation study to dig deeper into the characteristics of these technologies, the way they affect the apparel product development process and see if the hypothesis stated by the vendor side is established by the experienced users of 3D, the independent consultants of the industry and the academic researchers.

"When you read about 3D online or in articles you assume it is widely applied throughout the apparel industry at all process stages with today's technology already; however in reality the full potential of 3D is not achieved at all in the clothing industry" (Negabhani, Appendix 1)

4.1 Advantages / Benefits

Some of the benefits the 3D digital product offer to the product development is less samples, faster prototypes, much higher quality earlier-on in the cycle, and ability to make decisions based on that (Barrie, 2015). Moreover, designers are able to understand the technical aspects more when they are working alongside the pattern makers as 3D design seamlessly integrate 3D models with pattern design. Pattern makers on the other hand, can visualize entire size ranges on screen, from the smallest to the largest sizes. At any time whatsoever, it is possible to pass over immediately from 2D visualization to the three-dimensional one and vice versa, and all the amendments made appear in both. This possibility is not insignificant and represents a truly incredible advantage (Papahristou & Bilalis, 2016).

Other 3D prototyping options like Clo3D (Clo, 2015) provide the collision detection—an effect used in realistic 3D video games—allowing designers to create a garment's layering effect—the biggest component missing from virtual garments (see Image 4.1). Designers can create puffs, pleats, and padding that they would consider in real life. A virtual product development is the one that simulates the human being, the cut and the fabric in extremely high quality. The cut quality is exact and the fabric display is totally realistic when the parameters are known (Lectra, 2014; Adeddoff, 2014).

Participants were drawn to discuss the advantages of this new technology. Again, we are going to divide the answers in the categories of Vendors, 3D expert users employed in apparel companies, Independents in use of 3D and Academics. What is one advantage for one company maybe a different advantage for another. (See Tables 4.1a, 4.1b, 4.1c, 4.1d)

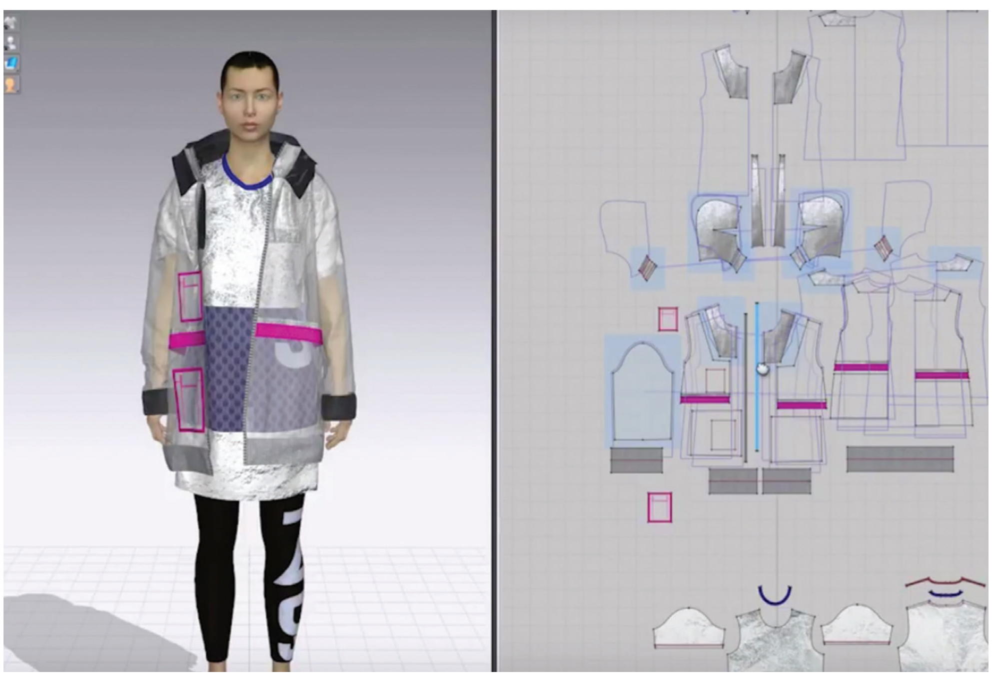


Image 4.1
Clo3d virtualising layers on an avatar

	4.1a. Advantages of 3D - Vendors
1	Speed of conception/Reduces time to develop
2	Reactions in sampling
3	Reduction in cost
4	Increases time to experiment/Allow more designs
5	Encourages communication
6	Eases communication
7	Better visualisation —> helps in presentation
8	Reduce physical samples
9	Reduces Errors when integrated with 2D & PLM
10	Streamlines the process ; keeps it more efficient
11	Better collaboration

	4.1b. Advantages of 3D - Independents
1	Affordable method of testing micro changes in prototypes
2	Instant Tech Pack & BOM (in Lotta/Browzwear)
3	Not only about reducing samples
4	Speed in making a physical sooner enhances the quality of the physical
5	More flexible visual to show your merchandising team, your sales team, retail team
6	Rapid prototype let the companies spend time in what they want to pursue right away
7	Right decisions; Silent decisions
8	Photorealistic products can be used in photoshoots
9	Integration with PLM & Design
10	Reduces carbon footprint

	4.1c. Advantages of 3D - 3D User Experts
1	Better work balance
2	Less iteration
3	Lower rate of misinterpretation (3D better than 2D flat sketch
4	Direct collaboration & usage by everyone; mutual language for different categories
5	Faster Decision Making
6	Visual Communication
7	Accuracy
8	Reducing Waste
9	Earlier Decisions
10	3D Digital much faster than physical
11	Reducing time for the design development & prototyping process
12	Much quicker feedback
13	Reduces defectuous products
14	Has the potential to reduce samples on the long run (hard to prove)

	4.1d. Advantages of 3D - Academics
1	Short lead time
2	Less cost
3	Better visualisation of design concepts
4	Enhances decision making
5	Saving sources
6	Quick integrated controls over the garment
7	Maintains the linearity between 3D changes and the 2D pattern
8	Speed

As we can see in the previous Tables, Speed and Fastness is one of the advantages mentioned in all categories. For this reason, we decided to ask the participants some quantifying questions. We later split independents in two categories (entrepreneurs and independents separately) due to significant different answers. Among managers and academics alike, it is widely accepted that three main factors impact NPD success: time, quality, and expense (McNally et al, 2011). Moreover, these three factors are not independent: changes to one factor impact the other two. Therefore, we asked the participants to quantify 3D prototyping technology in terms of development time (1 to 10; 1—very poor and 10—excellent):

Question 1 Time to customise product per design specifications

Question 2 Time to produce more variety in designs

Question 3 Time to change the design easily

Question 4 Overall design speed

Question 5 Time to introduce new products into production

Question 6 Speed in introducing new information

The results and the evaluation for each question regarding 3D technology in clothing NPD in terms of development time are shown in the following Figures 4.1a–4.1f. Although the collected data from participants is very limited, it is interesting to see the responses between the categories and the average evaluation for every question.

With an average of almost seven (7) and a significant difference between the entrepreneurs' and the academics' quantification it is obvious that the time to customise product per design specifications depends on the product. The simpler the garment, the higher the garment, explains Sascha Lanninger (Appendix 1). This explains the high number in the UX professionals.

Figure 4.1a
Question 1 (time to customise product per design specifications)

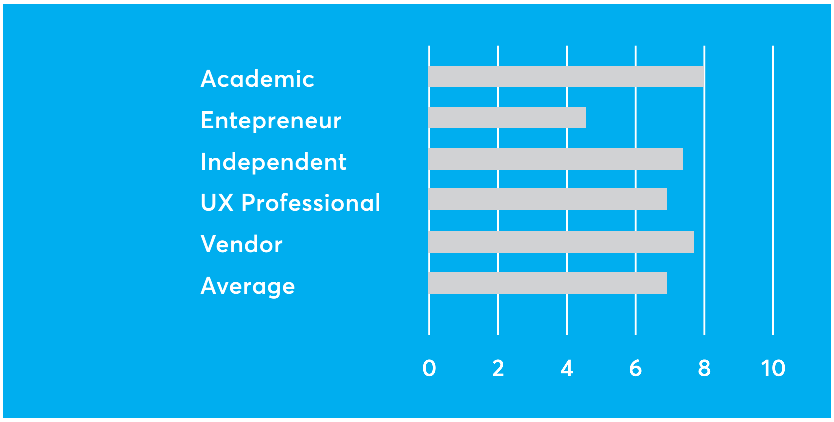
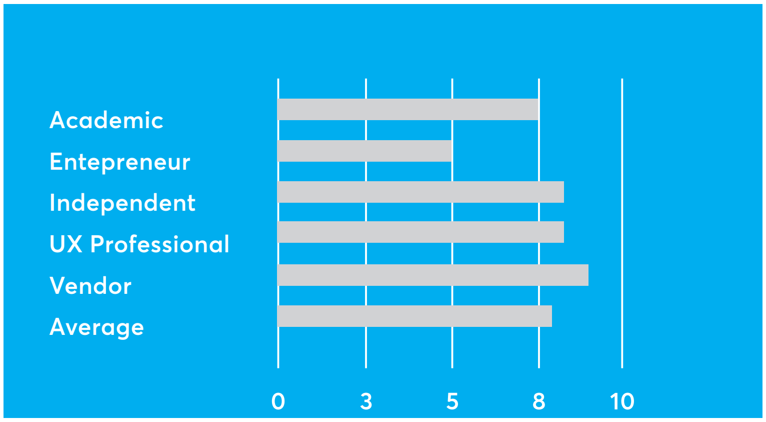


Figure 4.1b
Question 2 (time to produce more variety in designs)



If a designer gives a basic T-shirt/block and the avatar/dress form is the right one, then the process can be fast. Entrepreneurs state that the technology needs to be much faster to be most productive, especially for outwear, suits and multi-layer garments that need a significant added time comparing to a basic T-shirt. (Fig.4.1a)

In Question 2: time to produce more variety in designs, vendors are the ones who believe more that 3D can accomplish that. UX Professionals score 8,38 in average, stating that it depends on the software tool; it depends on the preparation. According to (Hartmann, Appendix 1), if all these are already done then the developer can produce new design variations quite fast. Entrepreneurs still are very sceptical and not convinced yet. If Design means changing Colours, Material, appearance (not folds/silhouette or patterns) the number is between 1–4. If it is a pattern, then also depending on the change it could be 1–4 but often also is 5–10. There was a vendor who could not generalise it and wasn't specific in giving a number in this question. (Fig.4.1b)

Question 3 was about time to change the design easily. In this question the category of the independents scored the highest average followed by the vendors (as expected) and the academics. In general again, it depends on the user. Some 3D experts stated that it is excellent (10) for an experienced user but they would put 7 (seven) for a non-experienced designer (Mithoefer, Appendix 1).(Fig.4.1c)

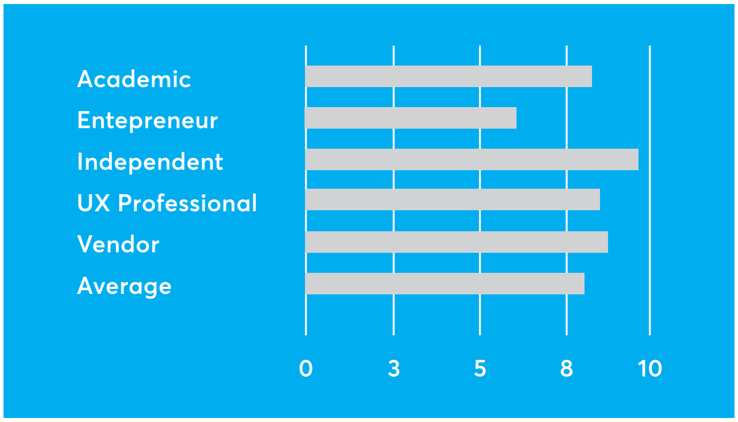


Figure 4.1c
Question 3 (time to change the design easily)

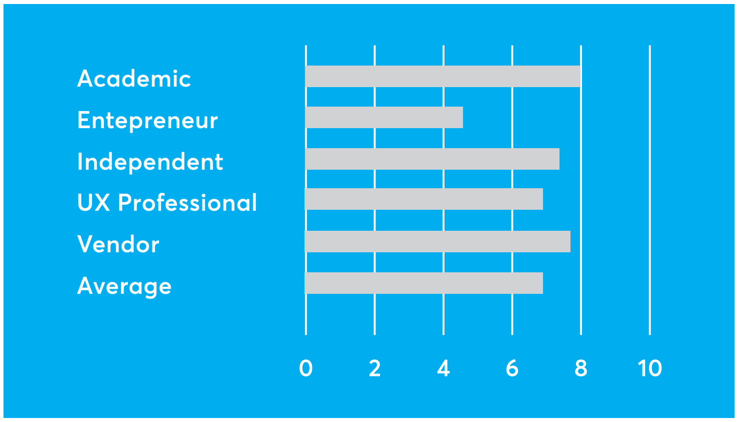


Figure 4.1d
Question 4 (overall design speed)

In the question that the participants had to evaluate then overall design speed (Fig.4.1d), again there were answers that mentioned the dependance of time to the 3D user efficiency as well the process behind it. Independents believe it will get increasingly faster like non specialised software design tools (i.e Adobe Illustrator) (Trautman, Appendix 1).

Question 5, time to introduce new products into production, scored the lowest of all with an average of 6.89. In this question even 3D experienced users argue that unfortunately the technology is not there yet, with the whole production depending still in 2D tools. Pattern is a big problem and at the same time always needed even in 3D environments. A design can be conceptualised in 3D space but in order to be finalised it requires a pattern with the appropriate grading on it. (Fig.4.1e)

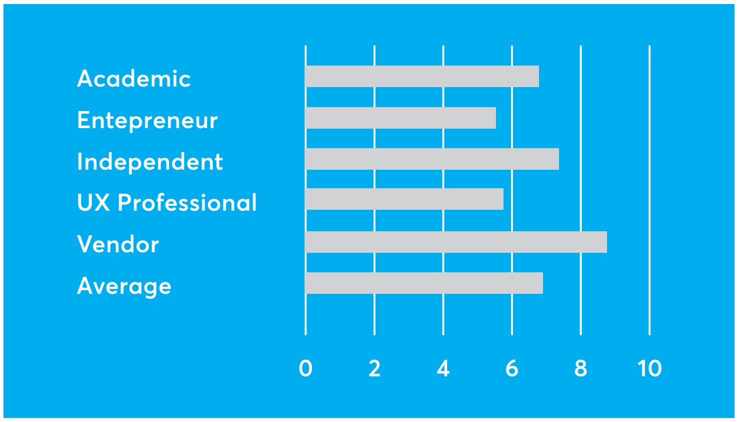


Figure 4.1e
Question 5 (time to introduce new products into production)

The last question (6) showed an average of 7,93 (almost 8) with 4/5 categories scoring high but again not excellent. (Fig.4.1f)

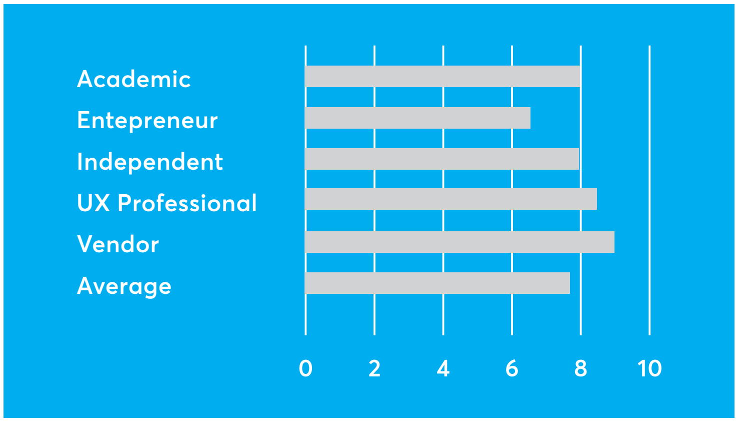


Figure 4.1f
Question 6 (time speed in introducing new information)

4.2 Disdvantages

3D in fashion is evolving slowly and will speed up, although it should and could have been years now. It is interesting to see how each category replied to the questions: "What are the disadvantages of 3D Virtualisation?".

From the vendors point of view, it has nothing to do with the technology of the software they provide. On the contrary, vendors believe in their products and claim that the technology is far more advanced, becoming more powerful and cheaper as opposed to the business situation which is becoming tougher and tougher. For the needed change, vendors give most of the credit to the factories. The problem to them is not the type of garment or how difficult and complex it is but the type of pilot of people would go to. According to CEO of Browzwear, it takes persistence and perseverance (Lim, Appendix 1). Some companies go into pilot stage and never grow out of this and some others start from difficult types like all the winter clothes. So to them, the most important factor is the difficulty to implement and the adoption.

Independent users of the technology don't see adaptation as a problem. As believers in the technology themselves, state that the software is improved in a much faster rate than it ever was before. Now the industry with leaders like Adidas, Nike, UnderArmour with experience behind 3D and Target, Coach etc, all these big corporations are applying pressure on the vendors to produce things that work. To them, ROI is of great importance (Harrop, 2015). Other independent participants reported the accuracy of the solutions that is not at the wanted level for the industry; that is the reason why many companies have moved it to Digital Prototyping solutions as being more of a concept and design tool (Young, Appendix 1).

Academics report the biggest disadvantage as being the lack of experienced users with technical knowledge. All the academic participants had one thing in mind; the time it takes to learn this new technology, and how insufficient the tool can become when comparing a skilful simple technician with an amateur 3D user.

Even so, these needed skills were ignored by many fashion courses in higher education run by non-technologists and non-industry facing or economics aware lecturers, and ineffectively developed by those inexperienced practitioners who focus on design only and are generally fearful of change. This topic is better covered in section 4.7.

The actual every day users and managers of the previous mentioned pilot projects in implementing 3D technology, make a list of disadvantages depending on how the company is fragmented, how many samples they produce, of what type the garments are, who is doing the 3D job and so on. For the project managers everything starts with the libraries. Certain materials and certain content like buttons, zippers and so on need to be available in 3D. This is a huge workload for the project team. The next obstacle is fabric properties related to the feel, drape and reaction on the body. The foundation of doing great things in 3D depends on understanding the complicity the relationship between the individual threads of the fabric.

"That is why the other industries have implemented 3D quicker, because the materials are so much different than woven and knitted fabrics"
(Harris, Appendix 1)

The next huge problem for companies who interact with their factories in Asia is the lack of communication between different 3D software tools. If the headquarters have one solution and the factory has another one, the exchanged file between them loses stitching information and the physical parameters used. Although the communication has been improved and the development team can do virtual iterations before visiting the factories,

"…dxf, the exchange format, is still missing a lot of information as with the CAD Systems" (Müller, Appendix 1)

Fit also was mentioned as a problem by many. Virtual fitting is not that easy. This is the reason that a physical sample as we explained in section 3.5.1 is needed; to check the feel of it, how the avatar reacts and moves with the virtual garment on. Avatars are explained in 4.5.2 but 3D avatar for many is not there yet as a fitting tool; “Fit was not as straightforward as what the demonstration was” (Alamachere, Appendix 1). Fabric properties as a disadvantage is remarked in the academic research of Behera (Behera, 2015). More specifically, analysis of the tailoring process reveals that mechanical properties such as tensile, bending, shear, compression and surface are equally important in the making-up process of the garment. The shape and size of the garment relative to the shape of the body, known as the fit, will be strongly influenced by physical and mechanical properties such as tendency of the fabric to stretch, shrink, distort, and drape due to stresses induced during use under static and dynamic situations.

To draw a conclusion, all people involved in 3D projects, from managers to end users, are optimistic about this technology. They want it to succeed. They employ designers, 3D artists, pattern makers, developers, technical people to make the process faster and they try to reduce the number of steps that are not giving feedback on the result of the user’s task. Companies who are very much design driven, with spoiled designers, everything needs to support the best design. If a software is too complicated, it wouldn't make it.

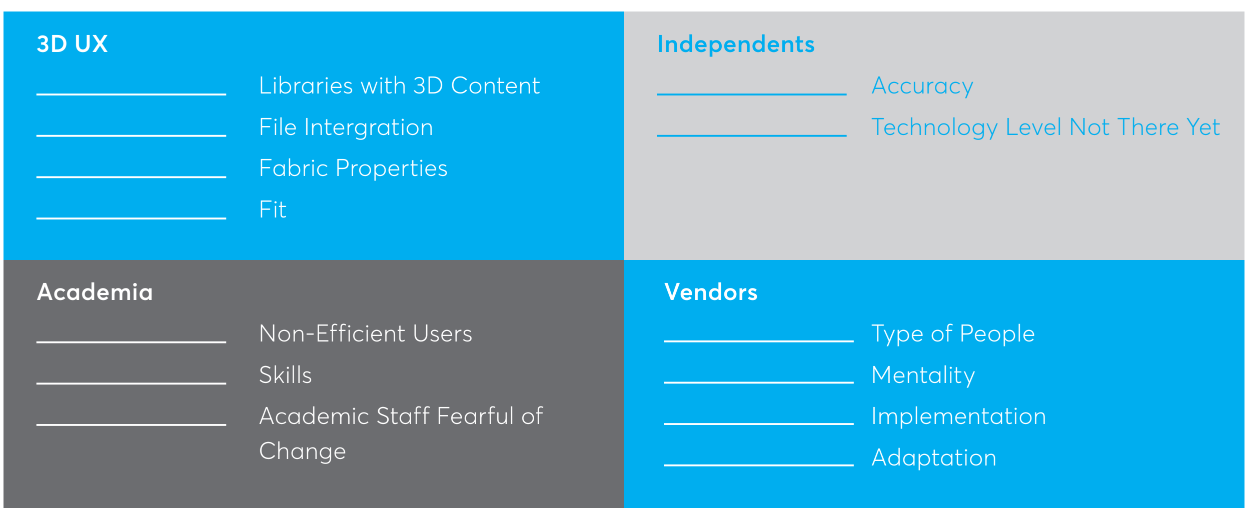


Figure 4.2
Disadvantages of 3d based on category answers

4.3 Objectives

After looking at the advantages and disadvantages of 3D prototyping solutions, the participants were asked to answer what are apparel companies aiming of this investment? In this question the vendors answered on behalf of their clients. The obvious answer and the main objective of this technology is to reduce the physical prototypes. It is not only the objective of the companies that make the software, it would be the industry's too; if it would be realistic to claim that for all apparel companies. As it was mentioned in the section 3.5.1, some big companies have improved their product development process, they gain time, they become more agile and gain more in terms of cost. Being able to do the first prototype in 3D (virtually) allow them to be much quicker and gain quite substantial amount of money. F&F, Target and VF (Jeanswear) have eliminated a lot of prototypes and they have calculated they are saving a significant amount of money (Pasarkamis, Gelis, Alamachere, Appendix 1). Directors of digital technologies in big sportswear companies, after years of piloting and implementing with 3D in their processes have come up to the conclusion that even though the initial objective was to reduce the physical prototype, it didn't work to the scale it was programmed and hoping to be.

It was really successful in many cases like reducing the number of versions of a model to be taken to the retailers and not reducing the steps in the product prototyping process though. There are many difficulties between what virtualization program was and to what 3D design program is at this point. 3D design is not so focused on sample reduction, it's much more focused on enabling creatives to be more likely to innovate in their process and to be able to help people make better decisions. Whether that's a small iteration on one line that they are working on a shoe, or to be able to see that repeatedly updating over and over again as they are working. So the aim was replaced by making it an end-to-end process; from design and pattern development, to factories and marketing.

It is not only about reducing cost; it changes how the industry works. The big players have one goal; to use visual assets through the whole process with the whole team using them—all collaborating in one same file and make decisions together. The ones who deal with 3D every day believe it will happen in the future but not at the moment, not the next year on a big scale. Why? People are still relying on physical prototypes (protos) to sell.

"If we would have less physical we would sell less product—and that would be a problem. So I am not sure we are completely ready to go completely into full 3D collection" (Sluiter, Appendix 1)

At the same time, Gerber Technologies (Gerber, 2016), takes 3D visualisation to the retail side. In the near future, 3D visualization will also extend to the consumer side of apparel purchases, with customers being able to visualize the fit of any garment on an avatar (or on themselves in an on-screen representation), and purchase this garment online once they are satisfied with the fit and appearance of their selection. Eventually, 3D modelling technology will make it possible for customers to not only make their selection, but to initiate a custom manufacturing process that transmits apparel manufacturing specifications directly through to the manufacturer to create a garment which has been custom-produced specially for that customer (Gerber, 2016).

4.4 Difficulties in 3D technology adaptation in the creative development of the clothing product

In previous sections of this Chapter, we analysed the pros & cons of 3D Virtual Visual & Prototyping Solutions. According to experts, the adoption rate of this technology is less than 10%; so there are barriers. Interviewees were called to pinpoint the difficulties that stand as an obstacle to the technology before the whole adaptation of the industry. Some participants claimed only one, others more than a few; depending on each one's individual experience and business work. Answers can be seen in the Fig 4.4:

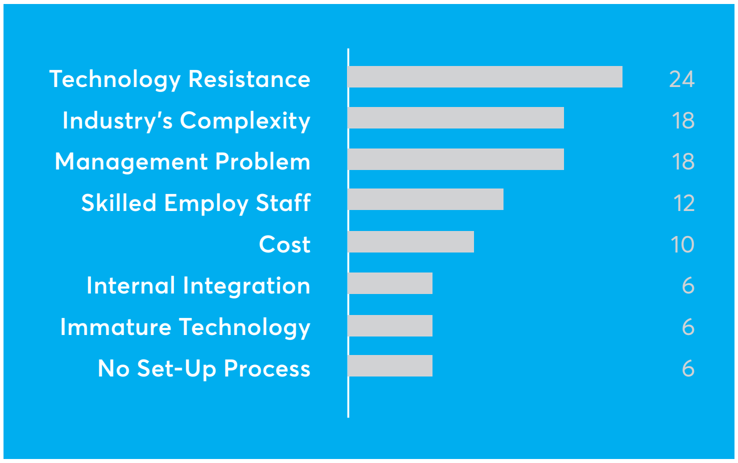


Figure 4.4 Problems in adaptation of 3d in %

Technology resistance: The No1 barrier is culture. The fashion industry is very oriented around design, look and feel, sketch; there is a lot of emotion around the design of apparel. Other industries (automotive, consumer electronics) with many technical people within the organisation, moving in 3D is very normal because they are used in technology where as in fashion it's very non technology driven area. People are not used to it; not used to seeing technology; it's a bit nerve-raking for them. In a leader company in sportswear, for example, which is very design-driven, design sets out the line and makes critical decisions. Designers don't like the interface of 3D prototyping; they find it too complicated.

It takes a lot of their time to understand how the seams are working.

"Design Driven means that we would make a change because of the design not because of the development process. Design for us is more important than that" (Sluiter, Appendix 1)

In smaller companies with more commercial focus a designer and a pattern maker could both be using 3D. This is a target market for some 3D vendors.

Industry's complexity: The complexity of the global industry and the complexity of humans, the variables:

- Different investments in different countries
- Different production
- Different access to different technologies

It is not realistic to expect everyone to be able to use it; especially in big companies where the processes are very fragmented with technical designers, creative designers, pattern makers, 3D developers, factories.

Management problem: the absence of a VP of R&D role in apparel companies is obvious for many. It is not a resistance from the end-users; be it designers or technical people. The problem comes from the upper management. The developers of projects in 3D acknowledge the reluctance of change and the conservative mentality at the upper managerial level. Unless the business has the vision, takes the risk, the initiative to invest, profits in the long run aren't gained.

"A lot of the older management people value profit maximisation over innovation and over new idea" (Couch, Appendix 1)

"If a company starts implementing 3D technology today, they are already behind" (Alamachere, Appendix 1)

Even if the company invest in 3D the effort doesn't stop there. Some managers in the past just handed—in a fairly complex 3D piece of software to the designers and the pattern makers, and just waited to be implemented. However, nobody within the apparel organisation had the time to stop what they were doing and start learning. The excitement and the confidence that it can work before rolling it out and the implementation begins, is not shared by the owner or the CTO (who would like to adopt the 3D solution). The benefits and the necessity of the technology are not well explained nor well supported.

Skilled employees: Most people in the industry who should be using those systems they don't have the skills to use those systems. Therefore, when they learn or when the new people get hired can the industry itself change (Haldre, 2015, Appendix 1). Internally, companies who have started 3D as pilot cases, need more people to support the 3D process and it is difficult to find them. Smaller companies face difficulties in financially supporting the skilled 3D experts. In both cases, those 3D tech savvy experts are hard to find when the practitioners are not using it in their educational experiences. In academia students need to be familiar with the use of technology. Whether it is adopted or not, whether it takes off or not; they just need to be trained how to cope with it (Ashdown, Appendix 1) (more in depth analysis in section 4.7.2).

High Investment cost: The problem smaller companies face is the cost of implementing such technology with a restrained budget. Many smaller companies have budgets that may not support the cost of technology like the giant companies can. Indeed, a design department doing the development with tools like Illustrator and Photoshop which cost less than $1000, cannot easily invest in a 3D tool with a price tag of $15.000. Implementation cost consists of equipment and software acquisition, training and support. Training cost in particular is usually forbidden for smaller apparel companies. When the technology can become more affordable, smaller companies will be able to utilise them.

Internal Integration with existing systems: New solution shouldn't aggravate with tasks of hands-on worker. The old existing processes work; a parameter usually forgotten when implementing new technology.

"We are not changing our technology because our current processes don't work. We make tones of products every season, it sells, we make money as a company and it's working. We think we can do it better. We really have to prove that we can do it better before we can change these things" (Asay, Appendix 1)

There is no set-up manual to describe what is the best way to do it. Most of the companies are building the new process from scratch and it takes very long time to fully adopt it.

Immature technology: In terms of standards or definition (material structure, fabric coding, etc) or for one person to create more than a hundred articles per season, while working on other season article and also maintaining any updated changes, it is not there yet (Malkosh, Appendix 1). High rendering of products in sales presentations are of great importance. Tools like Lotta for the design and colour-up and V-Stitcher for simulation and communication with the factories may work fine. For high quality rendering, engines like Modo or Maya are preferred externally, in order to sell a whole look with combined footwear, accessories etc.

In total, the vision sounds lovely, but a true end-to-end integration is still not an out of the box process. It requires strong financial power, willingness to innovate and change. Something that only a few companies have (talking about end-to-end vision such as Adidas lives it) (Lanninger, Appendix 1).

4.4.1 Time to implement

It depends on the company's structure, the type of garments they do the size of the company, what the communication level is; it varies. Sometimes analysis begins months before implementation. Typically, the vendor business partner, has 3–6 months analysis, then moves it on with a pilot, with some test users for another season, then the season thereafter the team can target a first implementation. Each employ has a different learning curve associated with it. In order to integrate the technology all technical designers need retraining. A conflict of interest with the brand usually arouses because it takes time away from actually making projects in order to take the training in these technologies. Integrating different technologies, not similar at all put the developer in the process of relearning tools and methods that have no common features anymore. When the 3D has been already implemented early-on in the company it takes from 2 days to 2 weeks training depending on the user. For someone who hasn't used 3D before, it takes 2–3 months to learn the fitting part. Another interesting issue addressed in the interviews was the structure of the training from the vendor companies to the end-users. One participant even called the training useless. Not because of the trainer, because of the content—for some till today, training is very broad. The trainer doesn't know the intensions of the company in the use of 3D and where to use it. 70% of the functions of the tool are not needed. The trainer should educate the user exactly on the work flow.

4.5 Challenges

In sections 4.1 & 4.3, we have exploited all the advantages and benefits that 3D virtual prototyping technology can provide to evolve the product development process to a new era. On the contrary, the implications and disadvantages are more than a few. Although all the interviewees acknowledge the significance of the benefits and believe that eventually it will happen one day, the biggest challenge that needs to be faced is PEOPLE. Fear of change, reluctance of change, challenge of change; people in upper management, people in implementing the 3D in their processes. Lack of dedicate people and resources to invest in the change. Many brands are afraid of taking the first step into this direction because they are afraid to make mistakes, to hurt their brand image, to neglect their heritage, the touch and the feel.

Some of the statements sound quite difficult to overcome:

"You can't make people to change. Nothing to do with 3D" (Trautman, Appendix 1), "for the designer it's hard, it's very hard at the very beginning" (Harrop, Appendix 1). "Only large corporations have the power to do that" (Lanninger, Appendix 1)

Academic research shows similar arguments.

The biggest challenge facing fashion's relationship with technology: overcoming a mental model that sees technology's role within the industry as a mere marketing add-on. Instead, what is needed at fashion companies is deep internal commitment of resources and a willingness to think and invest in increments of time that are much longer than a fashion season (Papahristou & Bilalis, 2016; Parkes, 2015). They need to foster a new ecosystem of players and build stronger partnerships between technologists and fashion designers. CAD in textile design came about 30 years ago. Many textile designers thought that they would lose their creativity, they would lose their jobs to computers. That wasn't the case at all. It was just another tool like oil paint and watercolour. The same is with 3D technology. The faster it works, the easier it is to use, the more creative people will just play with it.

When we talk about transformation of the product creation process, it implies not only changes to people but processes too. Having to create more styles in a shorten development cycle time (lead times not exceeding a couple of weeks), is a huge task for designers who are already rushed in the timelines in 2D processes. Those development or Technical teams, can feel "attacked" when it comes to changing their daily life/tools they work with. Large corporations try to refine them, build nicer interfaces and by balancing resources, people, timing of the planning and of the tools they expect the payback.

"We need to create product, we need to do a design cycle that forces us to do loads of iterations and end up with good quality result that people are willing to accept the design at the end" (Asay, Appendix 1)

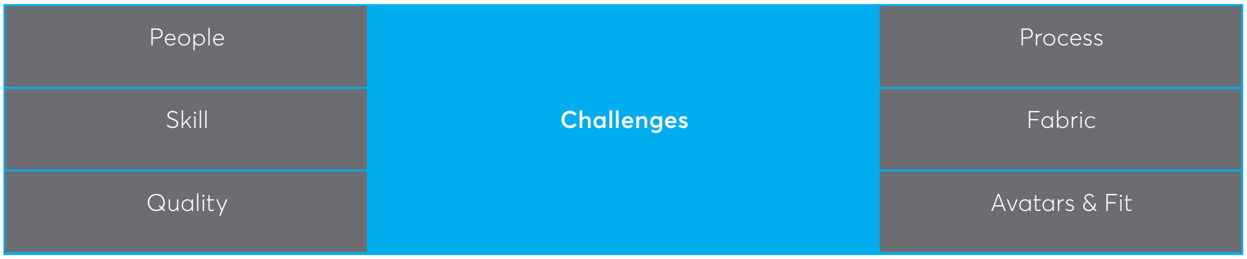


Figure 4.5
Challenges in the adaptation of 3d in the clothing industry

One of the biggest fears in the fashion/apparel industry is to destroy a process that is already working; changing something that will put everything down. What they are looking for is someone to secure them that by implementing a new technology will keep everything working and they will release the collections in time. As it was mentioned before, 3D processes are fairly new to the industry. Some companies are stuck at a point where they have got the tools allowing them to work but don't allow them to work as quickly as the designers are used to or would like to.

The speed of the whole technology vs the speed of the new technology and not just the specific features in it and their performance, but the overall workflow and process and what it means for the people to use these tools is hoped to be reduced as an issue. Even more so, acquiring 3D technology on such a scale is not cheap, talking about an integrated vision with PLM etc.

Avatars and fitting problems are reported as another challenge by indecent experts of the industry. Every human is asymmetric, with lots of personal specialties, the system's Avatar isn't. This creates some difficulties to think on and which are needed to calibrate, the real model vs. the digital one. Fittings still have to be done in person many times. A fitting cannot take full place in the virtual sphere, it still requires someone to give feedback on the fit and to discuss the fit. These discussions about a real personal fitting and a fitting on a fit model dummy are well known and we will thoroughly exploit them in section 4.6.2. Susan Ashdown believes that in terms of the validity and reliability of what it is actually displayed on the avatar, there is a long way to go and there is a technical barrier to that (Ashdown, Appendix 1).

In order to accurately represent what is happening with that fabric around the body you really need to get down to the yarn level and be able to understand and duplicate what happens which each yarn operating on the fabric and around the body, operating with the whole system. “That will take more research”. In the meantime, companies in the industry treat the fabric as a surface, as a 2D object and they try to give that surface behaviour based on certain measurable properties. In the following sub section 4.5.1 we are discussing the process of material scanning in order to fill the digital libraries with tested digital assets as they call them; virtual libraries that provided 3D tools are lacking of the required variety.

4.5.1 Visual Material Digitalization

Virtualisation of 3D materials has always been painful for the apparel industry. For some companies who have implemented 3D creative tools in product categories with a certain amount of fabric types and variations, perhaps virtualising hundreds of materials may not be needed. In sportswear companies though with hundreds of thousands of materials that have been used, are used or are to be reused again and need testing, its a huge work load and time intensive. Accuracy is being pursued; to be gained the fabric needs testing.

In the past, the virtual representation of fabrics was not so realistic due to the lack of not enough properties. Today it is a lot better (Goecmen, Appendix 1). Who is going to make the digitisation of the fabric? A pattern maker cannot put neither the physical properties nor the parameters of the materials in the system. A scanning device is needed along with an expert. The Director Creation Technologies of Adidas reported that there are some very sophisticated tools out there of material scanning but it takes forever to scan. However, several technology solutions have entered the market like Vizoo’s xTex scanner which creates textures automatically: Color/Diffuse, Specular, Normal, Displacement, Roughness, Transparency/Alpha. (Image 4.5.1b) and Dassault’s Delta Scan (Image 4.5.1a).

Image 4.5.1a

Image 4.5.1b

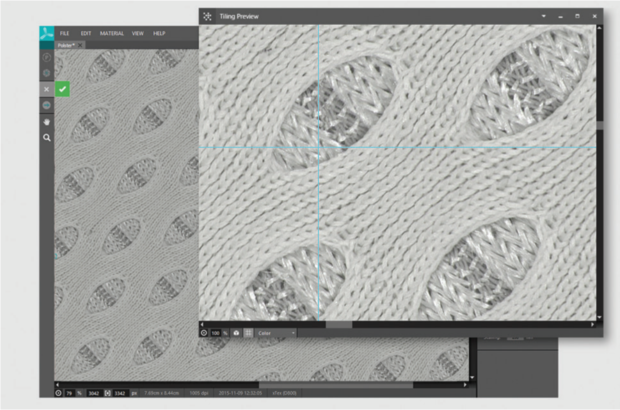


Image 4.5.1c

Image 4.5.1a
Visual material digitalization & management *Source: Dassault*

Image 4.5.1b
Knit material scanning with vizoo xtex *Source: uizoo*

Image 4.5.1c
Virtual library with fabrics/ materials integrated in 3d software *Source: optitex*

These scanners capture real materials into photorealistic visualisation in a few minutes—including depth and light reflection effect—and intergrade with 3D visualisation software like Optitex and it is loaded in the virtual library (Image 4.5.1c).

4.6 Need for total integration

The new and emerging 3D virtualized technology promises reduction on physical samples, shortened lead times, efficient production, earlier and quicker decisions, competitiveness, improved communication, even increase in e-commerce sales. However, this new technology is rarely seen fully integrated even in giant brands. Instead, as the research showed, even those doing the heaviest R&D and are the earliest adopters of technology and science into their product design, have started with small pilot projects with the hope to bring it on a large scale for the whole company. Technology evolves with them, improving, trying to become more intuitive and accessible. In the section 4.4 Integration was underlined as one of the difficulties in 3D technology adaptation.

Indeed, integration not only helps but is the key for 3D tech to be successful and be utilised by many in the future. 20 years ago, not all companies used CorelDraw or Illustrator; many apparel designers were still following inflexible and archaic working practices (Gill, Appendix 1), drawing in pen, photocopying and faxing hand drawings on hand drawn tables on tech sheets and stapling fabric samples. According to (Taylor, Appendix 1), although this is very historic, it is important to remember how changes are increasing in speed due to new technologies.

Today, designers create a digital design asset in Illustrator, Photoshop or wherever, then developers create a 2D pattern of it, someone else designs textile print ideas in Photoshop and all these integrated to one final tool with 3D representation and finally sent to a cutter with a visual look of the fabric, lined-up and ready to cut the garment. Software solutions and devices are all working together. Dxf-astm, Aama format files from any 2D system can be exported and imported to any 3D tool. This is the vendors' point of view.

Actual users with expertise in digital technologies all through the sample development, state that although the technology is improving constantly, 3D technology is one of the hardest to integrate because each department uses it differently and enormous collaboration is required.

In previous sections we have talked about how important 3D technology is for design based companies. How can the industry expect designers to fully work on 3D environment one day when “ai” files are not totally integrated yet? For example, 3D design and visualisation tools import “ai” files and create a separate “ai” in its structure. If the designer wants to do changes, instead of doing them in the original “ai”, he/she doses them in a separate file. In the situation where a graphic needs to be placed, he/she needs to combine it again to a new file; a too complicated process. Also, adjustments of fit are done in 3D then the developer has to go back to “ai” file and put them in. Better integration is definitely needed.

Creating clothing that fits and functions both for individuals and for a retailer’s target populations is also a crucial to an apparel business challenge. New tools and software for body scanning and product development enhance the ways that sizing and fitting can be addressed; they provide improved methods for classifying and analyzing the human body and new ways of garment prototyping through virtual product development (Gill, 2015). Significant, related changes are also being made in the fashion retail environment, including innovations in virtual fit to enable consumers to engage with fit online. Examples of these innovations (for more analysis see Section 4.5.3) like Virtusize, TrueFit, fits.me help reduce returns. 70% of the world’s garments are still coming from the back-end. It is still decided what the consumers asks for. “In reality that is still how the world is. Companies like these, address the problem in the front-end. In 3–5 years time companies like fits.me would push their business model” (Lim, Appendix 1). Therefore, giving access to different companies with real information about your size and shape, integrating information end-to-end, seamlessly from design, to manufacture, to retail, to sales and vice versa would create a total connected industry.

4.6.1
The pattern of the garment is getting intelligent

All our clothes are getting smarter. Will we have a pattern in the future that thinks by itself and transform by itself? There have been approaches to build tools to fix the fitting problems as discussed but they are nor perfect yet (Cuevas, Appendix 1). When the technology evolves to a level where each individual customer has access to his/hers body shape and measurements from any kind of body scanning, and all this data connected, analysed and integrated from a database on cloud direct to existed technologies of 3D prototyping development, then the software could identify which is the right garment when a person enters a store or an e-shop. Even within an apparel company, internally, some participants think that we are moving towards cloud solutions where people will have access anytime they want to work. People are more remotely located, companies are getting so massive to some degree that they either can't gather everyone in one place or they have problems recruiting the quality of talent they need to be in one place.

"As far as for the sharing of the information 3D can help communicate and help clarify some points and questions or remove them completely" (Bell, Appendix 1). *"In the old days everyone may had to use the same system but not today, because the output of 3D can be in html—is available in cloud today" (Lim, Appendix 1)*

In the near future, 3D visualization will also extend to the consumer side of apparel purchases, with customers being able to visualize the fit of any garment on an avatar (or on themselves in an on-screen representation), and purchase this garment online once they are satisfied with the fit and appearance of their selection (Gerber, 2016) (Image 4.6.1).

In the meantime, this is fantasy for the time being and companies are trying to find the appropriate way to set-up 3D into their processes effectively and accurately.

Image 4.6.1
Future extension of 3d visualisation to the consumer side of apparel purchases *(source: gerber, 2016)*

4.6.2 Avatars

Achieving well-fitting garments matters to consumers and, therefore, to product development teams, garment manufacturers and fashion retailers. The Chief Collaborator of Tukatech argues that a fit form (a replacement of a live fit model) used by brands, cannot move to really assess the fit. Something that fits a static form may actually be very uncomfortable when performing daily tasks like walking, sitting, or reaching. Without the proper foundation body shape and real-time feedback, it's difficult to have consistently good-fitting garments (Crawford, Appendix 1). Based on the vendors point of view, any body scan can be replicated in a 3D virtual model. At the end of the day, it is ALWAYS about getting the fit right and pleasing the target market. Theoretically, fit models should be chosen to represent the target market yes. Avatars in 3D need to provide the shape somehow.

Companies who have been scanning human bodies of different target groups can advice and provide the apparel companies with appropriate fit blocks and avatars. 3D creators and users are not satisfied with the avatars in the solutions of this new technology.

"The avatar is not like the human body, it's static more like a mannequin. You have to bare in mind that those avatars are static and not able to shape something, sports bras etc" (Mithoefer, Appendix 1)

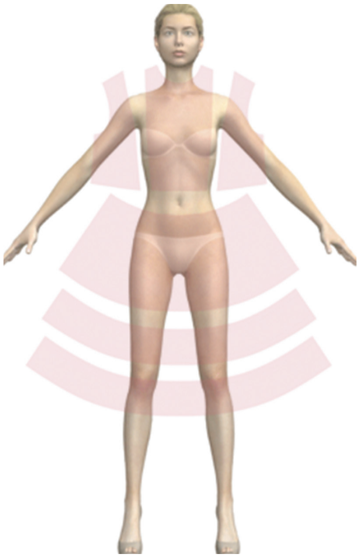


Image 4.6.2a & 4.6.2b
First step of virtual product development (up) and final simulation (down)
(Source: clo3d)

Others believe that the avatars are sufficient but there is definitely room for growth and in the future we will see a growing need for bespoke poses, photorealism and personalized avatars.

Independents, state that the technology companies waste so much time trying to have a perfect avatar that looks like the customer and they hire all these gaming engineers to create a product that still doesn't solve the problem.

Using NVivo, we try to run queries to find out how often do the interviewees have used the word avatar, in the conversation to have an idea how important the issue is. (Fig. 4.6.2a). The word "Avatar" with the word frequency query resulted in 20 interviewees with 49 references and most frequent rate in those that had "Independent" & "Academic" as an attribute. Vendors used the word in their phrases less often. In the following Figure we see the Word Cloud as well created by NVivo Query based on Selected Items-Nodes-4.5.2 Avatars. The result can be seen also in the right side of Fig. 4.6.2a.

Generally, it's a question of having physics on the body—for the moment in all the 3D tools, there are physics in the fabric and the system will calculate (based on the specifics of the fabric) how the fabric will drape on a solid shape—which is a mannequin. In the near future we will be able to have a body with also some physics and we will be able to simulate and see how the fabric pushes on the body. Images 4.6.2a & 4.6.2b, show how 3D body avatars, body scans or dress forms are the starting points of 3D virtual prototyping and the final simulation of sewn patterns and fabrics.

4.6.2.1 The end of average

The garment industry is trying many decades to typify standards sizes. Even in 3D, average represent the average fit model of a specific target group. In reality every single size is different. The whole concept of finding the fit model and that the fit model is the average person doesn't work any more (Ashdown, Appendix 1). Todd Rose in his book "The end of average" explains how we succeed in a world that values sameness" and states that this assumption is scientifically wrong. The sweeping generalisations of averagarians, as he labels them, cannot but gloss over the multifaceted nature of an individual. The effect is pernicious in the extreme. Rose wants the system to fit the individual, not vice versa, and thinks it can (Rose, 2016). There is a powerful drive towards the customisation of garments to fit personal body shapes which with the technology side-by-side will be called to face this issue. Table 4.6.2.1 presents the sources of Body dimensions data.

Table 4.6.2.1

Body Dimensions - Data Sources	
Standard Measurements	From published national or international size standards
Anthropometric Data	Measurements from data bases such as, CEASAR, SizeUK, SizeGermany or 3D BodyScanning
Size Labels in Different Brands	Developed from the above sources and or evolved from professional knowledge of customer market profiles.
Personal Measurements	Taken directly from an individual by manual measurements or body scanning

4.6.3 Customized clothing for proper fit: Illusion or Magic?

To help overcome barriers like product returns due to lack of proper fit & improving the customer experience, more and more retailers are adopting third-party online fitting services like iSize, fits.me, Metail, TrueFit and so on. These, powered by Virtual Scanner platforms are solutions that provide several brands with valuable size data, analysing its target market more accurately. Tools like these are built from industry developed interfaces, however they have the capacity to place the individual customer more centrally in the process. (Gill, Appendix 1). However, these developments and the suppositions on which they are built, raise the difficulties of existing subjective and undocumented practices which underpin existing clothing manufacture. For instance, there is an assumption retailers/manufacturers would even know how to integrate this new data; scanning data. This increases measurement data by up to 5 times what was previously used. Retailers used to work with 20 measurements and suddenly they would need to use 140 dimensions in their product development. The vendors of these solutions state that they transform the way products are designed, produced, and supported. We asked the participants if they believe that these tools change the product development process and how do they integrate with CAD & 3D visualisation.

During the process of using the described above online platforms, people are leaving valuable information to the retailers and the brands.

1. Data-information about the body size, the body shape (this is part of important info when designing garments).

2. Fit preferences (would they like to wear the garments loosely fitted, tight fitted,) and that applies to garments designs eventually.

A participant in our research project and Co-Founder of one of these Virtual Fitting Room and Fit Recommendation solutions, believe that these platforms could offer virtual prototype a few solutions:

— Nothing to do about digital prototyping at all but rather about the real life mannequins. On his opinion digital prototyping is quite sufficient for most garment types, however sometimes there is still a need to put the garment on a real person and see it worn.

"The problem with real people as we know today, is that fit models are not scientifically chosen and they change in shape and size" (Haldre, Appendix 1)

In section 4.5 Challenges, we demonstrated that Avatars and fit in virtual product development process is one of the issues needed to be addressed. In section 4.6 we concluded that total integration from retailer-to-design with shared information on shape and size is one ring of a total connected industry chain. Analysing the data from the participants answers on the question about Fit Recommendation start-ups and similar solutions, we find a relation based on the same challenge in both technologies (Virtual Technology in Product Development & Virtual Fit Recommendations): The problem of fit.

To most of the interviewees, fit is a matter of preference, fit is subjective and everyone is a different shape and size.

4.6.4 Connected end-to-end data

Data; Body Scanning data, Body Size data, Fit preference Data, 3D viral garment data. So much data, so many companies collecting information but nothing yet integrated. As it can be seen from the Fig.4.6.4a, as these technologies are used today they are focused at the front-end of the apparel's industry supply chain; after the garment is sewn and finished. Although both technologies are called to face the same challenge it has not got much influence on the product development process other than POS information determining the style and colors of products targeted to develop.

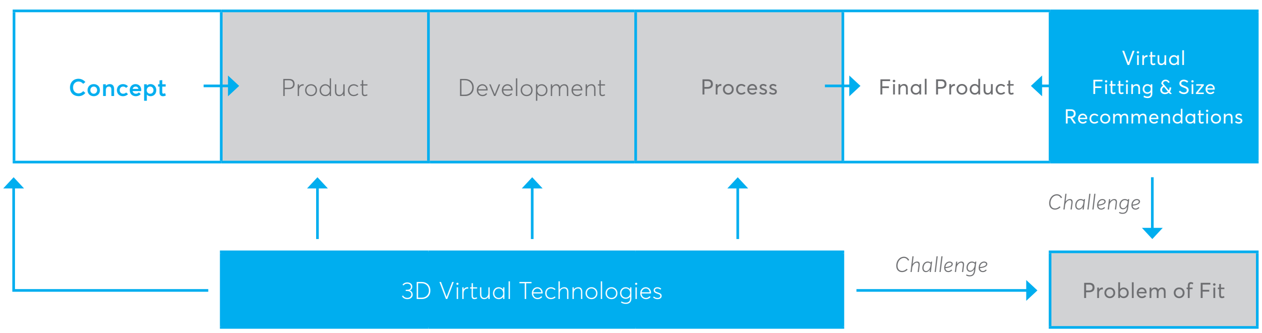


Figure 4.6.4a
The problem of fit

CAD/PLM integration is essential for supplying retailers with accurate brand recommendations for better fit. 3D visualization also helps, but it would depend on fit information being sent to the retailer, from finished goods measurements. At the moment, these platforms can allow the customisation to start which now typically cost more. Although data information is not integrated between sales, fit preferences and product design and development, many of the participants see these tools becoming mainstream. Virtual fit technology will be more available with better platforms and integrated 3D software. It will take some time. Time for the retail side to accept technology and push the integration backwards. Retail is going through transition where all the focus is in the retail space.

As thinks grow up and the consumer is comfortable seeing to an avatar of themselves and trying on clothes, creating analytics based on on-line fit tools could be a smart approach. It is going to take some time for the right people to convince the brands what to do. Also at the manufacture side the product development teams need to understand what a heat map of a virtual fit means and how to make pattern adjustments based on that. Hopefully the experience side of what retail brands can do with virtual fitting and unique customer experiences will improve. It's very similar to where things are with added manufacturing and tools that enable unique products for individuals to be made. Things are so close but they are just not there yet (Asay; Couch; Birnbaum, Appendix 1).

As it can be seen in the Fig.4.6.4b if and when these platforms integrated their data with the product development side and manufacturing of garments then perhaps the problem of fit will not be such a challenge after all.

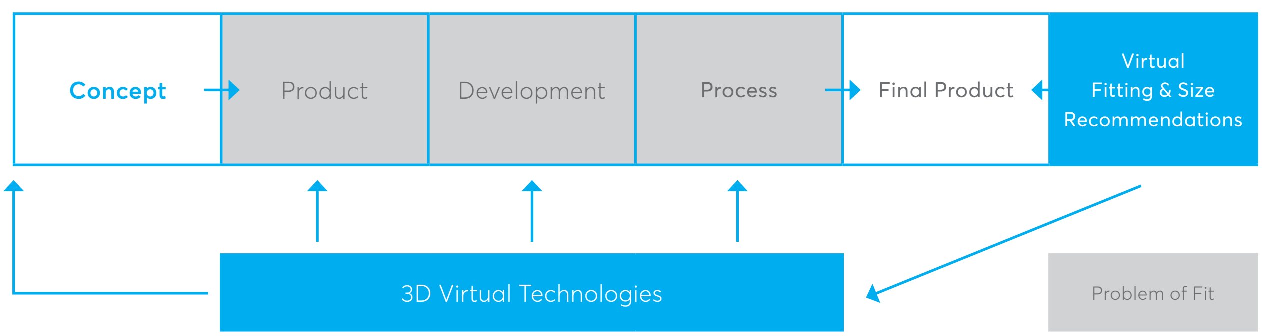


Figure 4.6.4b
Conceptualisation of integrated virtual fitting & size technologies with 3D prototyping

4.6.5 Multidisciplinary collaboration at all stages of the development process

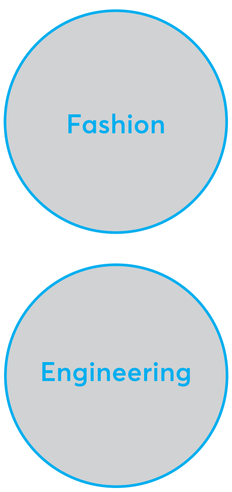


Figure 4.6.5a
Fashion & Engineering two different worlds

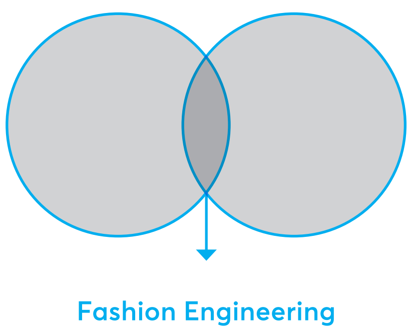


Figure 4.6.5b
Fashion Engineering collaboration

Whoever starts research and investigate in these kind of technologies needs a team. When it comes to cross functional teams, this applies to fashion companies as well just as much as to any other company in the world. The more collaboration between the teams, the better the products, the better in-touch with marketing the consumer. The products dominated the list of, in the cross functional teams, the business people. It's not just the designers in that list, it's the marketers who talk everyday to the consumers who see who those consumers are and what their needs are. If we think of all the knowledge it takes to be a software developer of a 3D solution and all the information needed to be a very good technical designer of garments, we would detect two different worlds especially for those developing the software. For starter companies both engineers and apparel people are needed and they need to understand and respect what each other has to offer. However, fashion and engineering do not mix. According to an entrepreneur and participant in a personal interview those worlds are so much apart that it's very rare to find people who are both engineers and understand fashion. This is one of the reasons perhaps fashion is adopting technology so slow. Fashion sense and mathematical engineering often don't grow in the same heads. Fashion and engineering is difficult because apparel has been reallocated to a lesser kind of art focus, a soft area that most engineers don't really believe that there is a knowledge and understanding of a different need. According to Susan Ashdown (Appendix 1) they are absolutely wrong. Apparel designers tend to side away from the engineering piece of it where they should embrace it. "We are in a situation where we need much better communication and collaboration". She even tries to do that in Cornell University. Addressing this issue, they had the idea to build a national network of Style Engineers[28] through collaborations and they developed a programme called Style Engineers, an NSF-funded partnership between Cornell University and the University of Minnesota, which uses hands-on activities to introduce young people ages 10 to 15 to smart clothing and STEM (Science, Technology, Engineering and Mathematics) through their interest in Fashion.

Multidisciplinary collaboration impacts positively in cost and quality of apparel products:

Cost — Working closely with design, the wanted design can be achieved partnering with someone that has 3D capability, making changes on the screen—a major cost saving expanding to time

Quality — Partnering with someone in design and someone with strong technical background can also resort in a better construction of the garment or simplify the construction as well.

We conclude this section quoting one phrase from two participants: 3D Product Specialist of Gerber Technologies and Senior Vice President Lifestyle of Dassault Systemes 3DXCITE:

"We need to merge good technology with intrigued limited skills and resources so that we can keep things going. Those are the things that have driven everything forward…" (Harris, Appendix 1)

" Just think of verticalization where you think RETAIL since the very first idea. In order to improve the collection and the process, we have to move all people involved closer together, esp. consumer and design. 3D and digital platforms enable the cross-functional, cross-site collaboration and facilitate that trend" (Lanninger,Appendix 1)

[28] http://styleengineers.org/

4.7 The Fashion Designer of the Future vs 3D virtual Prototype

The product development process is a cycle which is related to a large group of people. Digital prototype in the textile and clothing industry enables technologies in the process of product development where various operators are involved in the different stages, with various skills and competencies, and different necessity of formalizing and defining in a deterministic way the result of their activities. Moreover, design specification, for production, has to be interpreted between different countries, cultures and languages, thus increasing the need for accuracy of information through enhanced visualization with reduced text (McCann, 2012). Visual communication, especially with 3D prototypes may clarify complex issues between researchers from different disciplines and bring research outcomes to end-users. In this section we will present the research outcomes of the personal interviews concerning the new role of the fashion designer in the 3D creative environment, their needed skills and how the educational system with the established courses, mentality and vision has affected the skills of today's creative clothing developer.

4.7.1 Needed Skill

In an industry that's feeding an ever growing appetite for 'the next big thing', and with constant consumer demand for newness, the pressures on designers will inevitably increase. We need to get quicker, slicker and more efficient at bringing product to market. The same source argues that by bringing 2D and 3D together, we will enter the next phase of the evolution of computerisation and visual illustration and concludes:

We've come a long way from that sheet of paper and pencil (Royle, 2016)

There is an opposite opinion that the Designer will—in the next decade—still use pen and paper (Lanninger, Appendix 1). Whatever the case, whether it's footwear or fashion apparel, unless we teach new designers and engineers the old ways of working then we stand to lose the artisan skills that are required to maintain great design (Harrop, 2016).

As previously discussed in Section 4.1, as soon as we move to a technical execution, 3D changes and enhances process.

Instead of moving to sewing a prototype, we first get a virtual impression of the style in 3D. This is done much faster and allows to take on alignments on creative details right on the virtual sample without leaving room for interpretation. Then, once those details are aligned, the sewing of the prototype starts. So the process remains, but is streamlined. Meaning, unnecessary rounds of prototyping are replaced by quick and interactive virtual iterations.

"People with a certain job description today will work differently in the future"

says optimistically the Director of Creation Technologies in Adidas. In Section 4.5, we identified skills as one of the challenges the industry needs to overcome. In addition, many of the participants strongly believe that most people in the industry who should be using those systems don't have the skills to use them. It is indeed difficult to find the right people not just to do a good job but the best job so that no one would question the virtual sample and ask for an additional physical one. Below we present the skills need for the future 3D development expert based on the answers during interviews:

- The future 3D design is a compromise between the two ideas of the design process: engineering which prioritise efficiency & design which is about intimacy.
- Someone with synchronised experience; to replace the tactile experience of the material with technology. Harmonious and sympathetic to both practices.
- Transparent skills.
- Well versed skills in pattern design, understanding of construction, how garments are sewn together.
- Creative pattern making skills (suggesting new patterns to design and not the other way round).
- Conscious design skills.
- Fashion design skills with expertise in pattern making and embracing 3D technologies as main tool for development.
- "Barbarian eye", ability to manipulate images to the point where the garment looks like real.
- Integrated in skills both in Adobe environments along with 2D pattern technology + 3D + PLM systems use.

In the following sub-sections (4.7.1.1 & 4.7.1.2) we will find out what are the seven ways to make the best designers even better in the future (according to Design Council) and who is going to be mostly involved in 3D development technologies in the future.

Design Council's 7 ways to make the best designers of the future even better

1. Building mindsets
Resilience to succeed and challenge the status quo

2. Skill Fusions

3. Collaborative working
Walls need to be taken down between subject areas and cross disciplines

4. Design is at aa fork in the road

5. Diversity to compete
Industry also has a responsibility to start recruiting individuals that break the mould of the current designer stereotype

6. Design for non- designers
Design approaches could be embedded within every discipline

7. Design literacy from early years upwards *We must build in design literacy at every level of education*

4.7.1.1 Designers of the Future

Design Council[29] in an attempt to identify the skills needed by the designer of the future and how industry and education can work together to ensure British Design stays ahead, presented the following seven key points (Reed, 2015) (Table 4.7.1.1).

As it will be also explained in Section 4.7.2 Education has a clear role to play. Future design talent is a product of education received from early years upwards. The professional designers of tomorrow should be encouraged for cross-disciplinarily mindsets in order to enhance cultural understanding and compete globally in the apparel sector. We see a correlation between what has been presented from the Design Council, the research project hypothesis that the required 3D expert from the apparel industry does not exist yet and the result that came out of the participants' responses.

[29] Design Council : Established in 1944 to demonstrate the value of industrial design in reviving post-war Britain. Now is an enterprising charity which works to improve people's lives through the use of design.

4.7.1.2 Future Expert

Noticing the educational and professional background of the 3D experienced users, we found out that there is a diverse profile for many of the participants. Most of them have been involved with clothing design since the very beginning but some of them had nothing to do with apparel since recently. Big corporations like Nike and Adidas, who have leapfrogged the proof-of-concept stage already and moved to 3D prototyping to accelerate wither the pace or the creative productivity of their design and development (Catto, 2015), have created teams with diverse design disciplines. From pattern makers, fashion designers, product designers, even 3D visual artists with experience in the film industry. Why? One of the reasons is because there are no experts in the market with the right skills. Another reason is that the film industry has been investing millions of dollars into visualisation and authentic realistic cloth simulation for several years now. Nike's Digital Creation Leader mentioned the need of skilled staff in their offices and factories in Asia. Although their support partner in 3D implementation has undertaken much of that effort, still the needs and demands are high. This is one of the reasons that they are not expanding the implementation of 3D prototyping in all the categories of their products. The team is growing but they don't have enough people yet.

We asked the participants who is going to do the 3D job in the future on their opinion.

We even proposed some choices:

a. **Pattern-Makers**

b. **Fashion Designers**

c. **A new expert that doesn't exist yet**

d. **A graduate from a new course with a curriculum combining 3D fashion design, engineering, virtual arts etc.**

The answers were quite intriguing. The academics stated that the future role is not clearly defined and skills of the 3D user in the apparel industry do not exist yet (c). They have agreed that new courses and knowledge are needed with combined disciplines from the areas mentioned in choice (d). The Individuals who are related with the 3D tools independently, also agree that a new expert is needed, (c). The 3D UX staff, strongly believe that they themselves are part of the generation, putting the foundation. They also point to the non-existing expert (c). Only the vendors are inclined towards a combination of (a) & (b). In particular, they believe that ultimately it will be the Fashion Designers as the tools will evolve to become intuitive like pen and paper. As 3D continues to develop it will start with pattern makers, then new positions will be created for 3D design. As 3D development improves and simplifies, it will return to the Fashion Designers because they will easily be able to communicate their design aesthetic.

"But also the developer/model maker/technical person will perform his job in 3D. Let's say it's a lifecycle and every role will add something to the 3D garment from concept to prototype to final reference sample" (Lanninger, Appendix 1)

Simon Kim, CEO of CLO USA, says the process will continue to need physical skills like pattern making.

"We don't go to the client and say, 'We want to replace everything in 3D'. We are trying to contribute to their processes so it can be easily adaptive, so they can benefit from it and so that it slowly gets the culture going," (Elias, 2014)

In order for this new expert to bloom, companies need to invest in the learning and development of their employees in order for them to get the most out of the current software and to keep abreast of evolving industry technologies. It enables them to maximise their potential whilst increasing company output as well as developing and expanding the skill sets of their employees in the process (Royle, 2016).

Fig. 4.7.1.2
Word tree for "Expert" created in NVivo with the Query function searching in Internal Data-Interviews.

4.7.2 The role of Education and the development of Employability Skills of students in Fashion/ Clothing Higher Educational Courses

It is clear from research that virtual garment visualisation and prototyping is set to play an important role within the garment product development in the future and it is essential that fashion and clothing graduates have an understanding of what technology tools are commercially available, the implications of its use within advanced product development and its benefits to the process. Fashion institutions should adapt their educational system in such a way that fashion professionals of tomorrow undergo the latest technology used in the industry. (Dhapodkar, 2012). Moreover, according to another study the academic institutions should provide industry-oriented courses to students and prepare them for situations they will face once they have entered the job market. In addition, the interaction between academic institutions and the industry needs to be improved by proper coordination (Nayak, 2015).

There are arguments that while these institutions deliver acclaimed design talent, they are unable to provide the industry-based experiential-learning opportunities required for translating innovative designs into marketable garments (McEwan, 2012). Most of the young generation students in fashion & clothing education have no hands-on experience of working with 3D, thus entering the technology-led business of modern fashion, unprepared. And while it certainly isn't endemic, since many universities have partnered with vendors of 3D solutions, there appears to be at least some gap between the industry's growing awareness and experience of 3D, and those of students currently in education (Hanson, 2015).

In order to research the issue we invited the participants to answer two questions:

1. In education and especially in the learning process of design, is the mentality evolving taking into consideration new concepts and environments like the one of 3D?
2. Is there enough academic staff with knowledge and mindset in designing in 3D virtual prototype?

In the first question most of the answers were Yes or For sure. However, the implementation is slow or is very far behind. To be on the cutting edge the institutions have to be part of the development process. The participants with the Attribute-Country of Work: US, replied that many universities already focus on 3D and offer special classes, slowly making an impact, starting to use it as important tool in their curriculum.

However, there are some responses which are quite conflicted to the Yes answer of the first question. Universities are either teaching non 3D or even when they do teach 3D tools in pattern making it is actually the 2D pattern making they are teaching. 2 reasons have been identified for that:

a. **There is a culture of apprenticeship, there is a tradition very evocative for many people in the industry; there is a system of the atelier. "particularly in fashion, technology has been effectively stopped developing in education by academics who are focused on a dream of haute couture and ironically fearful of change" (Taylor, Appendix 1). That needs to be replaced by a more technology to be more realistic in the current environment that we live. There is a long way to go.**

b. **Lack of knowledge and willingness to open to technology; resistance. Many tutors of fashion and textiles courses are stuck in this schism of the past. They are scared of change. Preparing new generations for those technologies is key to unlock the technologies potential.**

Participants with the Position Attribute: Academic, strongly believe that it is responsibly of influential Course leaders, Professors and Deans to intelligently understand and reach out to experts, lecturers, technicians, and researchers in 3D (physical and digital) subjects and also the consultants and retailers in industry to enlighten conventional or narrow and historically restricted experience. The aim would be:

To input new 3D thinking and inform investment in school, colleges, universities which can positively communicate to apply change management approach

Invest time and intelligence in teaching effective 3D technologies to improve communication in global industry, reduce the number of samples and waste, improve testing of materials and process to improve negatives such as pollution and environmental issues (Taylor, Appendix 1)

In the second (2) question ALL the participants replied NO except a vendor who said: “Too few”. Some replied that it will take at least a decade for everything to evolve to the right level. More academic people are definitely needed to drive the “becoming intuitive” of the technology. More educational programmes are needed to bridge the gap between the technical expert and the code developer.

In academia students need to be familiar with the use of technology. Whether it is adopted or not, whether it takes off or not; they just need to be trained how to cope with it (Ashdown, Appendix 1). If we don’t allow the new technology to be learned by the students on undergraduate courses then they will never be able to feed that back in or invest that learning experience either back into courses as teaching demonstrators or into the industry (Taylor, Appendix 1).

4.7.3 Wrong people in wrong positions

3D virtual prototyping technology in the fashion industry has been thoroughly explained in this chapter. Fashion is not like any other industry. Fashion is multi-sensory, fashion is about perception, is so much about value; about inartistic value—a very unique industry. Technology and especially 3D visualisation and 3D apparel modelling has been researched and monitored for more than fifteen years and the industry struggles to implement and adapt it. Resources are key to any technology implementation. We believe that the industry and academic research institutions were looking to this technology through a very narrow computer-science or engineering-focused lens, for too long. It is obvious that there is a huge gap between what the industry needs and exists because wrong people are in charge of all this technology. Big corporations are inviting experts from computer science or 3D visual arts to support fashion designers or pattern makers but have no experience in connecting the process with making a product that is relevant to the fashion customer at the time. They are not designing; they are supporting. Designer and pattern makers on the other hand are still very attached to the old-fashioned way of working (quite controversial if we think of the word "fashion") and still resist to fully implement a designer's mindset of thinking and working in 3D environments. As we explained, it is incredibly difficult. Many courses and lecturers or heads of department are out of date and the students know this. Creating a new role with new skills coming from new courses (perhaps digital) will bridge the fashion-engineering of art & science gap with confidence and right resources.

4.8 Case studies in Using 3D Virtual Prototyping - 4.8.1 Successful

As it was expected, there are more successful stories that failure ones. We have asked the participants to present their cases, their way of working, their route to success. We visited Adidas-World of Sports in Herzogenaurach (Germany) to interview a team dedicated in 3D Virtual Technologies because they are industry-leading in further developing the 3D technology.

Virtualisation has been a strategic initiative for the Adidas Group since back in 2004, after they proactively began to look into how the automotive and aerospace industries were successfully showing their products using digital 3D technology. After so many years of trials, today they are asking for it; graving for it. They have put a sigh "3D is not the enemy" 4–5 years ago which is still there! By working with some of the most cutting-edge software, the team behind Digital Creation has started a small revolution and through pilot projects (involving many designers, pattern makers, developers, factories) they tried to find which is the best way to do it. Their designers have very good drawing and sketching skills whether in hand or in digital suites like Adobe etc. Working with the vendor software companies they have built customised tools to enable their designers' workflows. They have given them a 3D environment to work comfortable in it trying to focus on that, than traditional 2D tools. As a result, they have established an innovative way of working with their suppliers, product creators and sales department to utilise virtualisation to its full extent—in a sustainable way. Especially in football category, it has been a successful collaboration tool and they rely on it for fit—fit and design gets approved early. Although they cannot provide everything the business is demanding because of resources, they believe they have the right tools, there is a lot of competition in the market but they are going to be a lot more ahead than the competitors in 3D.

Another successful case study is the one of VF Group and especially the Jeanswear collision of VF U.S. (Image 4.8.1). With dedicated resources and dedicated staff to learn the new way of working in Browzwear's V-Stitcher & Lotta 3D environment, the VF Group overcome the initial scepticism for the 3D in apparel industry. The inceptive behind the original investment in 3D was reducing the number of physical samples as well as the number of creative options and process steps behind marketing 3D internally. They have applied 3D to design, pattern making and fit, and even to merchandise to fulfil their goals. For technology is very important to them, as understanding (or not understanding) fit models and 3D avatars make a huge impact on sample iterations. The initial challenge was to achieve a comfort level in visualising samples virtually instead of physical. It also took time to engage the pattern makers until they used the software for c-developments. Today every pattern maker is equipped with a powerful laptop (Accumark & V-Stitcher) and in 2014 they made 275 virtual prototypes, reducing the cost of physical samples by 50–75% (Gardner, Appendix 1) and almost 90% of their products in their department are fitted virtually.

Image 4.8.1
Examples of 3D virtual prototypes in Jeanswear
(Courtesy: VF Group-Jeanswear)

4.8.2 Failures

At the beginning of 3D implementation there were quite a few failed methods. They started with bringing in a team of people from pattern making and design; they would train them on the software and then let them try to do their work. That method almost always failed because they were interested in 3D tools, they wanted to add it to their profession and their professional skill set, but they didn't have time to use it. Digital prototypes that were coming back, looked correct but they didn't meet the need of the teams so there were a lot of big early failures. The implementation became far from successful when they realised they need to train the factories, they needed to use the same software and help the teams with the workflow. Until that point the company and the dedicated team was not able to show an end-to-end benefit of the digital prototype process (Appendix 1).

In this question vendors could not mention any of their clients but they saw some smaller companies failing as they adapted technology but were not living it on a daily basis. When the tough times during a season came, the knowledge already was gone leading to less "success" when using the technology and this then becomes a vicious circle and ends with the client abandoning the technology and falling back to the "old world's" processes. Another testified case was one company's which started the 3D but because the top management wasn't totally convinced, little by little they came back to the old way of working. Or another company very excited with the 3D, doing sportswear for basketball players. In this situation the mannequin wasn't tall enough, and exact in morphology like an athlete, and limitations like these prevent the vendor from providing their customer with a 3D solution. The solution should be to scan those athletes but those athletes were not available to be scanned so that became a problem.

"If you take a step then make it right and do not neglect it. Because then, you might better not even take the step at all" (Lanninger, Appendix 1).

5

Sustainability

5 Sustainability

"Sustainability" is an ubiquitous word, usually associated with environment. However, sustainability also embraces economy and society (Blackburn, 2009). Some authors, define sustainability as the balance between three elements: economy, environment and social equity (Frankel, 10998; Elkington, 1998). More recently, (Fiorio, 2015), reports that sustainability means public awareness of the future in many different fields: environment, society, economy. In the industry, in order to be competitive one has to be sustainable. However there are others who argue that much of the 'complexity' of sustainability is lost when considering only the three mentioned aspects (Gilding, 2000). According to (Gardetti & Torres, 2013), sustainable development is not only a new concept, but also a new paradigm, and this requires us to look at things differently. It is a notion of the world deeply different from the one that dominates our current thinking and includes satisfying basic human needs such as justice, freedom and dignity. In this chapter we will associate sustainability also with technology in the product development process so as to achieve desirable fashion products. How can we use the prolonged technologies examined in previous chapters and at the same time reduce the use of resources and the generation of waste.

The global fashion industry (which includes clothing, textiles, footwear and luxury goods) is worth an estimated $3 trillion (Companies & Markets, 2013), and according to McKinsey (2015) has "outperformed the overall market and every other sector across geographies for more than a decade"—more profitable than even high-growth sectors like technology and telecommunications.

In a disposable culture, fast-changing trends and cheap manufacturing means the fashion consumer can throw things easy without a second thought. Fast fashion or pre-made fashion, has brought a democratising element to options and choices that the consumer has never had before. The fashion consumer fuelled by rapid consumption buys clothes that may never wear, dispose of clothing that is still usable, and simply buy excess garments to satisfy psychological needs (Cao et al, 2014). According to WRAP, every year in the UK only, 350.000 tonnes of used clothing, worth of estimated £140 million, goes into landfill (Sims, 2016). The fact that the production and use of fashion garments generate a great amount of waste, would make it appear as an impediment for sustainability (Gardetti & Torres, 2013). The fashion industry fundamentally operates in an unsustainable way and cannot carry on business as usual (Ditty, 2015).

As awareness on fashion's impact on our world is growing, there are key leaders in the industry who are beginning to question the impacts of the model built on careless production and endless consumption. The pace of innovation in technologies (applied to the product development phase) is reaching the stage where it can keep up with consumer demand in markets like these. We will examine if 3D Virtual Prototype, 3D visualization, 3D Body Scanning and virtual try-on technology on conjunction to solving the proper-fit problem, can help the clothing sector meet green targets, without damaging the environment through wasteful manufacturing processes.

One of the biggest problems fast fashion companies face is the constant challenge of productive relationships between internal departments (separated by silo mentality), processes, solutions, as well as those between external suppliers, their processes and technology solutions (Harrop, 2015). CSR (Corporate Social Responsibility) regulatory compliance and operational effectiveness add to the previous challenges and apparel corporations require to take action. New digital solutions are supporting PLM and CSR programs operating across the entire end-to-end Supply-Chain addressing to the needs today's complex apparel sector.

[30] WRAP: Waste Resource Action Programme

The purpose of this chapter is to document first, the concepts of CSR and Collective actions on Sustainability (Fig. 5). It is argued that most of the sustainability issues should be addressed during the design stage.

Figure 5
Word Cloud for "Sustainability" developed in NVivo analysing all the transcripted interviews of the participants

Through our research a number of research questions were investigated such as: Why has the industry's view of sustainability been difficult to monetise, even if the new model of fast and accelerating fashion is more complex with higher environmental impact? What are the challenges need to be addressed in order to manage emerged issues like the reduction in the use of intermediaries between producers and retailers as means of delivering a more transparent and sustainable fashion product? Why are these issues threatening retailers on operational effectiveness? In what way does the fashion industry approach the social and environmental challenges emerging from the supply chain? Can new technology solutions like PLM (Product Lifecycle Management), 3D visualisation or 3D prototyping work with and across supply-chain partners to reduce the environmental footprint of their processes? Can fit problem solving, extend the useful life of clothes and reduce the environmental impact of clothing in use through design and services?

The final intention of the project in this chapter is to present a new apparel product development model, encompassing various digital tools which aim at addressing the above research questions.

Common elements of CSR are: 5.1 CSR

a. A reliance on meeting or exceeding the letter and spirit of legal, ethical, commercial and other business requirements; and
b. A focus on the impact of a company's operations, products and services on people, communities and the environment (Wakelyn & Chaudhry, 2009).

The globalised production of textile and fashion goods has made it more difficult to regulate standards with regard to environmental impacts through a "single country policy". The development of CSR programmes in development countries has occurred in response to increasing consumer interest in social and environmental impacts of business activities wherever they operate in the world.

CSR refers to actions or business practice that companies taking responsibility for ethical and environmental concerns. Usually, it's a banner under which small businesses and multinational corporations alike have emblazoned on marketing materials online and in-store (Childs, 2015). Ideally, well-managed CSR creates social and environmental value, while supporting a company's business objectives and reducing operating costs, and enhancing relationships with key stakeholders and customers (Rangan et al, 2012).

Although it provides numerous benefits like Figure 5.1 is showing, the fashion industry have just recently realised its importance and significance. According to an interviewee, deeply involved in sustainability, the fashion industry responds in what the consumer wants, spending great amounts of money on marketing, trend-forecasting and so on. If the industry steps up and makes:

A product that is more expensive to make,

a. Is more expensive on the rack and
b. Not sure the customer will want it, then that is a recipe for
c. disaster from a fashion perspective (Portway, Appendix 1).

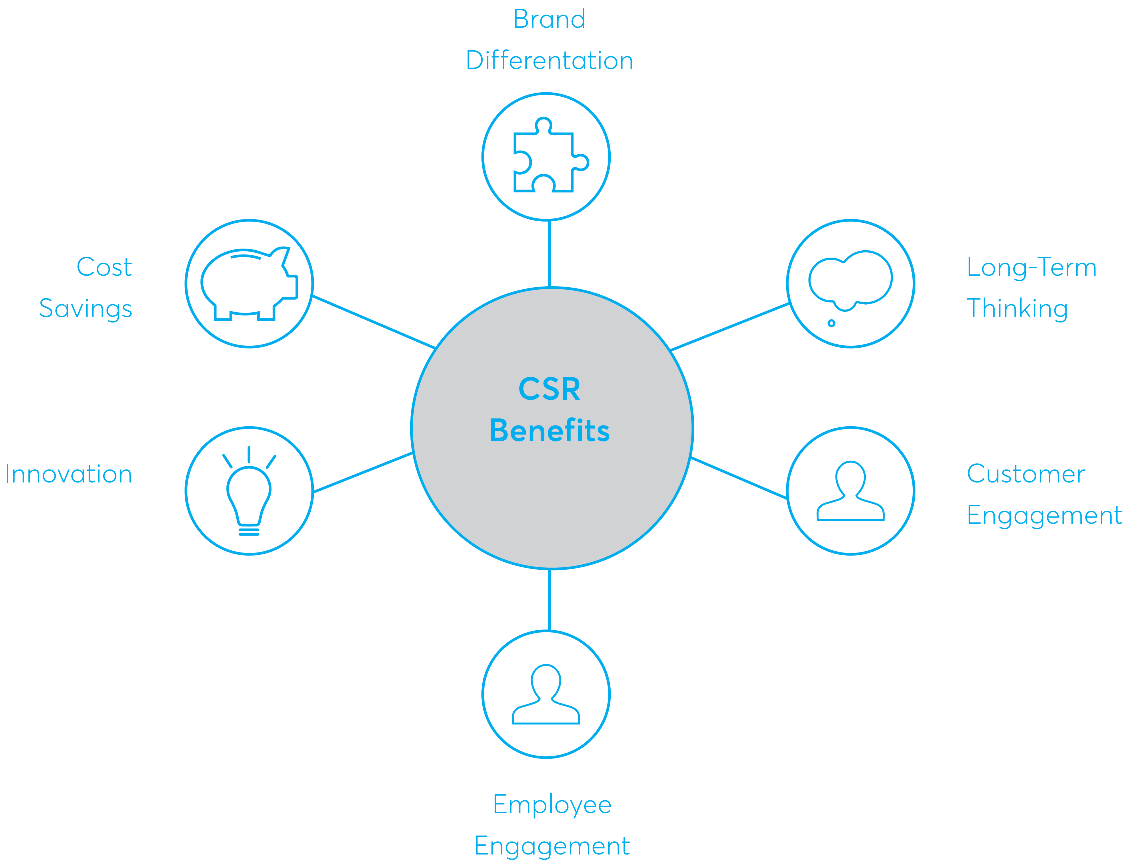


Figure 5.1
CSR Benefits

The fashion industry's approaches to the social and environmental challenges that emerge from the contemporary supply chain are limited because, so far, it is not profitable. There is an emerging movement though, from consumers who expect brands to play bigger roles in their communities through corporate social responsibility (CSR) initiatives that help support their collective well-being (Ethical Fashion Forum, May 16, 2016)

5.2 Collective Action on Sustainability

The more immediate challenge in CSR remains the management of public perception and the avoidance of negative association between the parent brand and ongoing ethical and environmental crises (Childs, 2015). World's leading fashion brands within the Sustainable Apparel Coalition (SAC) share the same vision as stated on SAC's website:

"The Coalition's vision is an apparel and footwear industry that produces no unnecessary environmental harm and has a positive impact on the people and communities associated with its activities" (SAC, 2015)

The Higg Index[31] (the core driver of SAC) delivers a holistic overview of the sustainability performance of a product or company (Fig. 5.2a).

WRAP, a UK resource efficiency experts organisation, influences the design of everyday items, such as textiles, and is helping to transform how we buy, use and dispose of these goods, especially clothing. Most of the brands are performing badly on the Higg Index (Portway, Appendix 1) showing how far behind and out of date companies actualy are (Birnbaum, Appendix 1) and the reason why the fashion industry must learn to become more sustainable. In 2013 the SCAP[32] 2020 was launched when WRAP identified key action areas that could deliver the biggest reductions in the environmental impact on clothing. The signatories represent 40% of the whole UK clothing market including Tesco, M&S, Next and fashion designer Stella McCartney (WRAP, 2015).The seven action areas of the commitment are as it is shown in the Table 5.2.

Another initiative is Sustainable Fashion Academy[33], the world's first online course. It has been launched as a new tool relevant for companies looking for flexible and cost effective training in sustainable apparel in sustainable apparel. Divided in six modules, where the fourth one is focused on how the product design can offer sustainable solutions, equips designers and entrepreneurs at the product development level, with the knowledge and tools they need to develop and drive apparel innovations and at the same time contribute to improve a company's sustainability performance.

31 The Higg Index (launched for the first time in 2012), is a suite of tools designed to allow fashion users—from factor managers to designers and sourcing teams—to drive meaningful change in their methods, and to minimise their negative impact on workers and ecosystems worldwide.

32 SCAP: Sustainable Clothing Action Plan

33 http://www.sustainablefashionacademy.org/ (retrieved 12/11/2015)

Figure 5.2a
Higg Roadmap

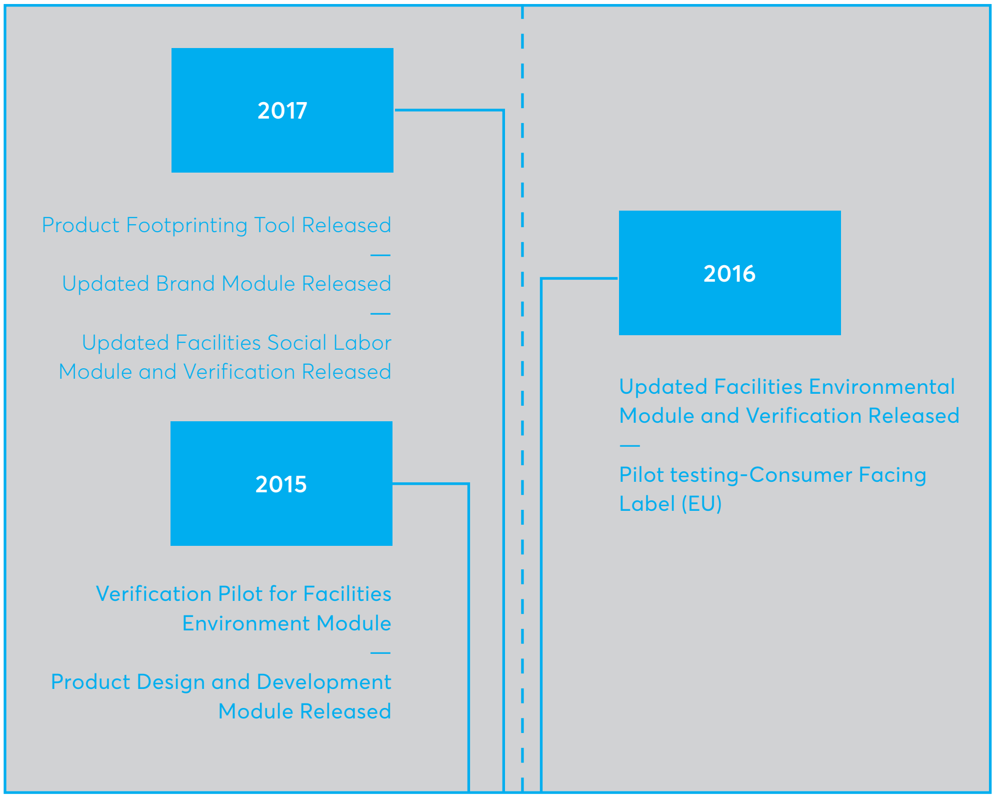


Table 5.2
SCAP 2020 Commitment: The seven action areas

SCAP 2020 Commitment - The seven action areas	
1	Use a common assessment tool to measure our baseline position and track changes in footprint over time.
2	Reduce the environmental footprint of clothing through fibre and fabric selection.
3	Over the longer term, work with our supply chain partners to reduce the environmental footprint of their processes.
4	Extend the useful life of clothes and reduce the environmental impact of clothing in use through our product design and services.
5	Develop effective messaging to influence key consumer behaviours which will reduce the environmental footprint of clothing.
6	Increase re-use and recycling to recover maximum value from used clothing.
7	Develop actions that help keep clothes out of landfill

In the Fig. 5.2b. are shown the most important stages during a garment's creation and use. Design is put in the middle because decisions that are made during the design phase can influence performance during all the other stages. Moreover, the stages are put into a circle surrounding design, because the process of making and using a fashion product does not have to end when a customer has finished with it. The material can have many lives; can be reused or recycled to create new fashion products.

5.3 Understanding the evolution of the Industry- More focus on Design and Digital Solutions

Today the fashion collections may be smaller, but there are more of them. Instead of having four seasons and four collections a year, the industry now has fifty two with new products coming in stores every week. Fast Fashion has become faster and more furious. This means more size, colours, and variations to manage. If we multiply that by the many geographic versions where the company is present, the complexity increases further. As fast fashion accelerates, and shoppers require their needs to be met at the right price and on the right day, retailers need to work harder to ensure ethical compliance in their supply chains (Cocozza, 2015). On the other hand, consumer is relenting in his demands and increasingly sophisticated; high quality, low prices and constant newness are what interest him today. The market is increasingly saturated and combined with the above, makes tried and true fashion strategies such as geographic expansion and internationalization more complex than in the past (Papahristou & Bilalis, 2015).

The collaborative supply chain is perhaps the most critical component of a sustainable business plan. Since many brands source from the same suppliers, collaboration also encourages the development of industry-wide standards, and adherence to those standards by the suppliers. In the long term, these efforts hold the potential to benefit a company's bottom line, driving innovation while offering consumers better quality products that are less likely to be harmful to people or to the environment (Cobb, 2014). Examination of the connections between design process and the supply chain is imperative for advancing sustainable practices in

[34] EPSRC is the main UK government agency for funding research and training in engineering and the physical sciences. The Centre for Industrial Sustainability operates out of 4 Universities—Cambridge, Cranfield, Imperial College, and Loughborough—with a track record of success in the core elements needed in sustainable manufacturing

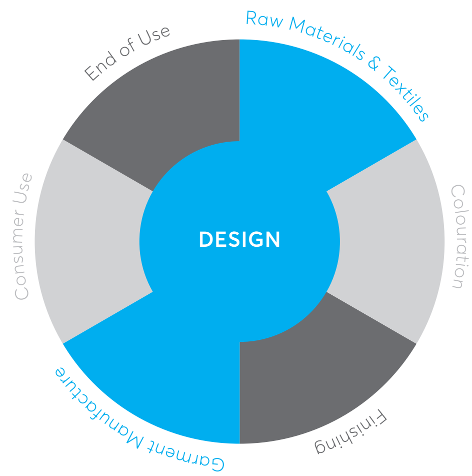
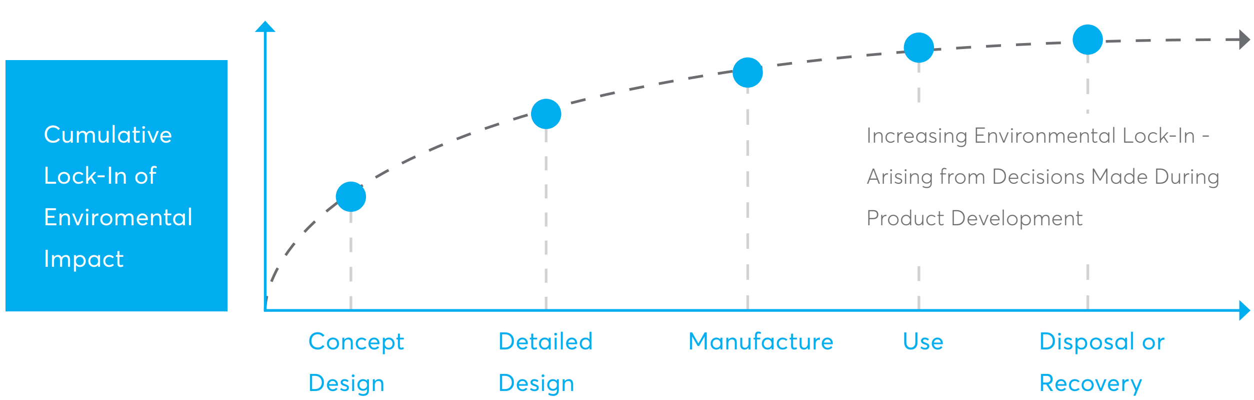


Figure 5.2b
The most important stages through a garment's creation

Figure 5.3a
The Importance of Design Improvements. Early Integration gives the greatest environmental rewards

the apparel and textile industry (Curwen et al, 2013). Indeed, according to EPSRC Centre for Industrial Sustainability[34], the majority of the environmental impact of a product is decided during the design phase, with most decided after only 20% of the design activity has been undertaken.

Several research studies have been contacted trying to embed sustainability considerations within the established product development processes of the apparel industry. Gam et al. (2009) incorporated cradle to cradle model (McDonough and Braungart, 2002) into existing apparel design and production models to develop a sustainable apparel design and production model C2CAD (cradle to cradle apparel design), to provide guidance for sustainable apparel design that addresses environmental and human health issues in the design process. The C2CAD model has four steps: problem definition and research, sample making (including "material selection and testing" and "cost and design evaluation" parts), solution development and collaboration, and production (Gam et al., 2009). The C2CAD model was applied in the design of children's knitwear (Gam et al., 2009) and men's jacket (Gam et al., 2011). The aim of the research was to design environmentally friendly apparel that helps solve consumer's excessive apparel consumption problem. The strategic evolution of the Design Process embedding sustainability into established design processes is shown in Fig.5.3a.



Fi

Fig.5.3b presents a word tree for “Sustainable” created in NVivo using the Query tool in selected node-sources (based on interviews).

This research project has examined how digital prototype in the textile and clothing industry enables technologies in the process of product development where various operators are involved in the different stages, with various skills and competencies, and different necessity of formalising and defining in a deterministic way the result of their activities. Taking into account the recent trends in the industry, the product development cycle and the use of new digital technologies cannot be restricted in the “typical cycle” but additional tools and skills are required to be integrated taking into account these developments (Papahristou & Bilalis, 2015). We agree with EPSRC’s developed framework, that the design process needs improvement so that sustainable design is not an afterthought, but is incorporated mentally through the design process from its outset (Fig 5.3c).

It is believed that 3D virtual product development and PLM innovations can create a change in the sector reducing environmental impact and promote social equity. This ensures that the lead-time in getting the prototype right is reduced and gives a customised final sample which is more sustainable.Indeed, these tools are not only making fashion better, faster and more profitable but they fall right in line with companies’ increasing desire for green practices: fewer prototypes mean less energy spent on shipping and transportation, less water and fewer chemicals used in preparing fabrics for samples before even creating and reduced waste. Some of the benefits the 3D digital product offers to the product development is less samples, faster prototypes, much higher quality earlier-on in the cycle, and the ability to make decisions based off of that (Barrie, 2015).

Results /Drive sustainability:

- No more paper pattern tests
- For some styles, no physical samples
- Over 50% faster

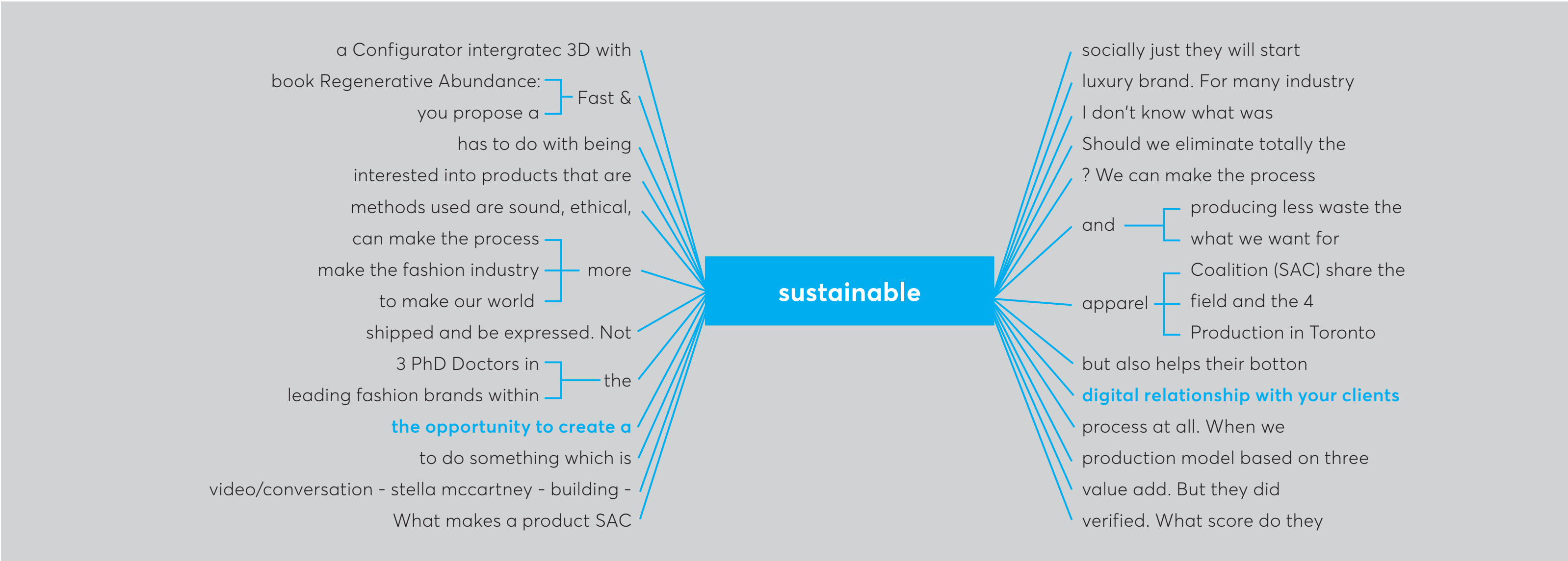
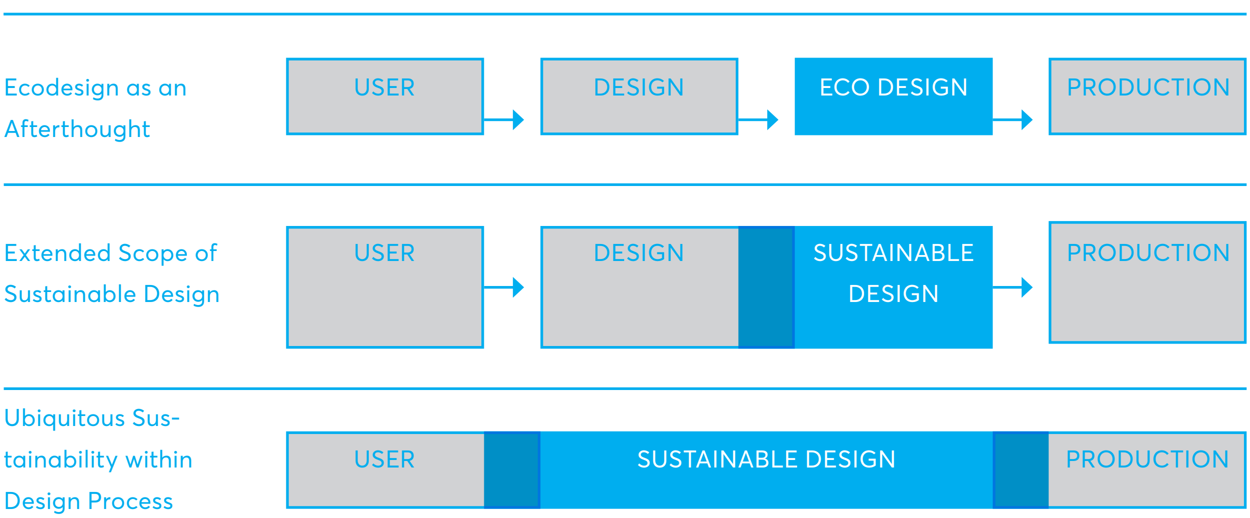


Figure 5.3b
Word Tree for "Sustainable" created in NVivo using the Query tool in selected node-sources

In Chapter 4, where we analysed Virtualization as an integral part of the fashion product development, we reported the designers' and users' experience towards 3D Design tools: it's a much complex thing, because a garment from patterns on to a 3D avatar needs more time than what most people think. Quite so, sustainable design implementation methods (like 3D virtual environment) within a company's development process, particularly in the case of complex organisations and products, need further improvement. In the case of apparel it all comes down to draping and proper fit, thus a significant development in avatar realism is needed (see also section 4.6.2).

Figure 5.3c
A Strategic Evolution of the Design Process



We have asked the interviewees if solutions like 3D visualisation or 3D prototyping in product development can work with across supply-chain partners to reduce the environmental footprint of their processes: most of them agreed that new technology innovations like the 3D prototyping can reduce numerous samples but point out that the truth is in the context.

Shipping of prototype back and forth, back and forth many times obviously happens a lot because of traditional prototyping process.

"The truth is though that we are talking about just few garments being produced which are just waste. If you ship back and forth one prototype and get it fit perfectly for the target market (obviously 3D prototyping is even better) but getting the prototype right even if it encores some waste, is more important than ending up with a prototype that does not fit the target market; instead you end up producing too much XXL size i.e. for the Portuguese market" (Haldre, Appendix 1)

Working to create better sizing fit and communication sizing fit can reduce the ecological impact of clothing purchasing.

"We trained our consumers to buy clothes, wear them once and if they are not satisfied with fit throw them away. I think we can untrain them" (Ashdown, Appendix 1)

We also asked the participants if they believe fashion companies share the same philosophy and show the same sensitivity towards green practices as vendor companies state they do (Lectra, 2015). The interesting outcome of the conversation with them was that although they all agree that 3D does reduce costs and environmental impact, there is a question if existing practices actually meet the targets the companies are setting for new approaches (Gill, Appendix 1). More specifically, most brands take this an important long-term benefit when thinking about scaling up the use of virtualization but it's not something the decision to go 3D digital is based on.

"Short-term, there are other, more pressing KPIs (Key Performance Indicators) that often matter to our clients" (Lanninger, Appendix 1)

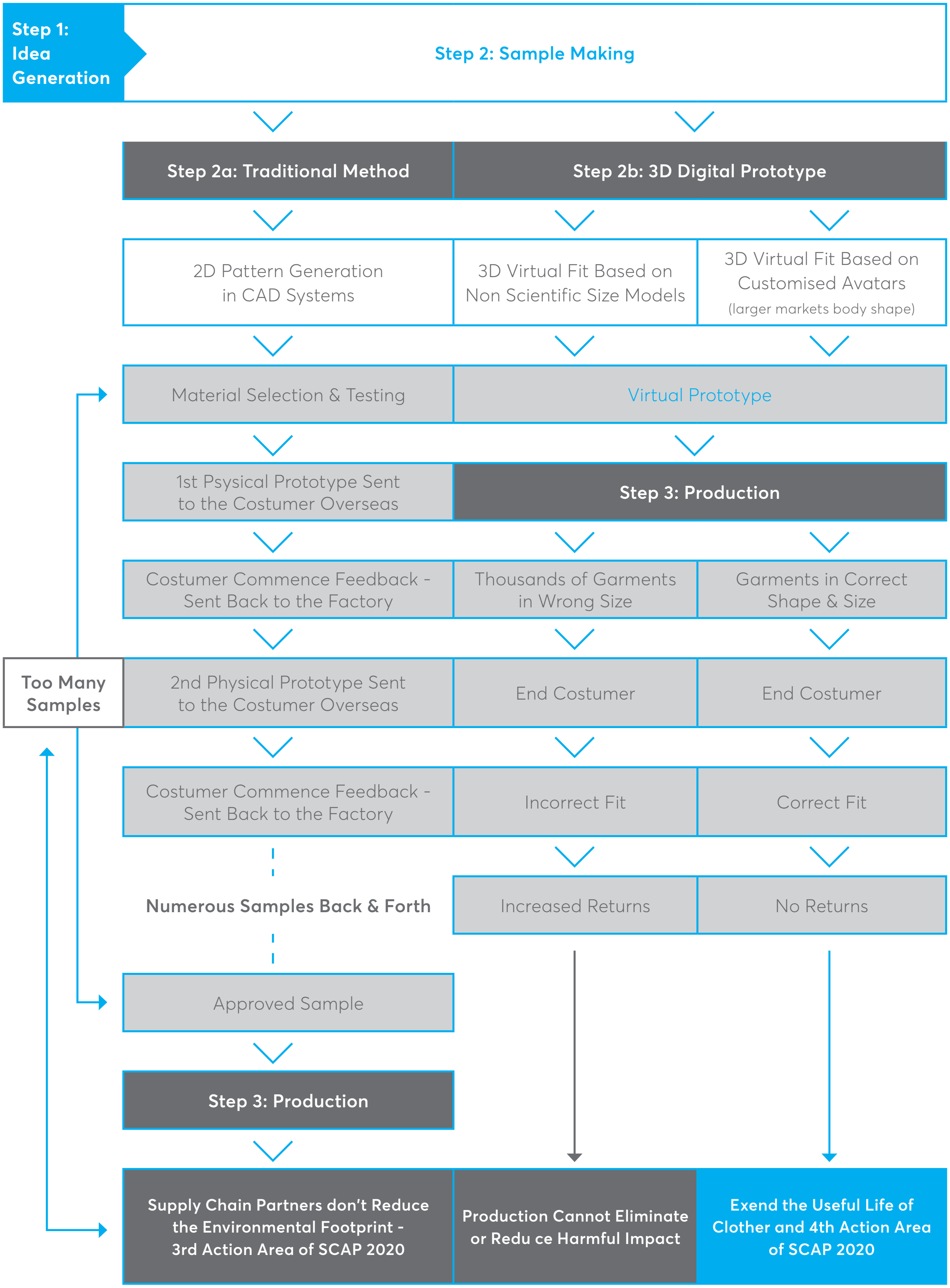
The Senior Designer 3D in a leading sportswear company reported that the company's short-term focus is more in some other areas; not specifically targeting 3D but looking at overall number of product reduction and gradually changing how they incentivise the sourcing of materials that are coming from better sources. The sample reduction was part of the hope around the virtualization before really related to sustainability (Appendix 1). Technology cannot solve anything on its own, it is humans who have to think and care and mainly develop a wider cultural view on connectivity and aligned business intelligences and governments that has to change (Taylor, Appendix 1).

5.4 Combining Technology & Sustainability to Create Products that Fit

In 4.6 section of Chapter 4, we presented the importance of total integration between existing 3D virtual prototyping solutions and innovations in virtual fit in the fashion retail environment. Fits.me has integrated even more this virtual sizing technology into the e-commerce shopping journey. It changed its robotic mannequin forms into human avatars, has increased customer engagement from 40% to 70%, and had a significant impact on reducing returns. Reducing returns means extending the life cycle of clothes; means less clothes out of landfill; means two out of seven action areas of SCAC 2020 Commitment are being met (Table 5.2).

All the above solutions are being developed at the back-end of the supply clothing chain. (Gill, 2015), argues that for best effect in the short term, such advances need to relate well to existing manufacturing practices and to the methods that have, over many years, become embedded by practitioners into the processes involved in clothing product development and those used for establishing garment fit.

Validate fit throughout the size range early-on
Decide which sizes to produce
Guarantee design integrity for each size


Step 1: Idea Generation
Step 2: Sample Making
Step 2a: Traditional Method
Step 2b: 3D Digital Prototype
2D Pattern Generation in CAD Systems
3D Virtual Fit Based on Non Scientific Size Models
3D Virtual Fit Based on Customised Avatars (larger markets body shape)
Material Selection & Testing
Virtual Prototype
1st Psysical Prototype Sent to the Costumer Overseas
Step 3: Production
Costumer Commence Feedback - Sent Back to the Factory
Thousands of Garments in Wrong Size
Garments in Correct Shape & Size
Too Many Samples
2nd Physical Prototype Sent to the Costumer Overseas
End Costumer
End Costumer
Costumer Commence Feedback - Sent Back to the Factory
Incorrect Fit
Correct Fit
Numerous Samples Back & Forth
Increased Returns
No Returns
Approved Sample
Step 3: Production
Supply Chain Partners don't Reduce the Environmental Footprint - 3rd Action Area of SCAP 2020
Production Cannot Eliminate or Redu ce Harmful Impact
Exend the Useful Life of Clother and 4th Action Area of SCAP 2020

We strongly agree and propose a more sustainable product development model based on two different applications of the 3D visualisation technology in the apparel industry:

a. The virtual try-on technology which mimics a customer's dimensions and displays what a certain garment might look like when worn, offering fit guidance solutions and
b. Virtual prototyping technology which tries to alter the way physical apparel prototypes are being made, making adjustments across complete size sets and reducing the need for numerous paper patterns, fit-checking and samples in the development stages. A model that integrates the 3D technology applied so far separately in e-tail of a finished product and in the design/development of a fashion prototype accordingly, enhancing the connectivity of all those involved-from the online shopper to the producer (Fig. 5.4).

The right technology can help brands and retailers to unlock new levels of transparency, and collaborations between sustainability organisations and PLM and extended PLM developers can drive these opportunities further.

Most vendors strongly argue that collaboration is a key word in technology. All the needed information and data is there (see also Chapter 6). It is just that they are not shared. Today everyone is collaborating. Effective collaboration (Gerschel-Clarke, 2015) between: a) companies which look at size analysis of target market, consumer shapes and sizes and produce size ranges and size studies based on fit preferences and b) software providers of PLM systems and 3D virtual solutions for the whole supply chain is the key to a new business practice that:

- **Improves the process by replacing unnecessary rounds of prototyping by quick and interactive virtual iterations,**
- **Creates a stable, transparent, sustainable and mutually beneficial channel between end-customers and clothing producers**

Figure 5.4 (left)
Sustainable apparel design and production model

The potential of 3D design helps to eliminate the large amount of waste that fashion faces, and it may also bring different parties involved closer to just-in-time manufacturing which is very important. 3D technology is a way to combat the unsustainable practices within the fashion technology (Couch, Appendix 1). The fashion industry as we know it today is over. In no way does it respond to the needs and values of consumers. Even companies like H&M and Inditex that are currently so profitable have yet to overcome the single most pressing issue of our time: sustainability (Birnbaum, Appendix 1).

A strategy and roadmap is needed for the clothing sector to work towards sustainable vision that is commensurate with try scale of footprint challenge. It is the attitudes and motivations of the technology users that will determine whether a more sustainable approach to fashion production and consumption is adopted (Scaturro, 2008).

This research study believes that if you can use 3D in the concept creation phase then the product development stage will increase significantly. Since different people are involved in the end-to-end development process, it's not a horizontal line; it is a loop. The earlier the designer can come with a concept, the earlier the birth of a concept can be visualised, the faster the people can make decisions on the style, design, colours, fabric, price, fit. The earlier you can have all this resolved, the better the decision can be taken; the more times you can have ideas evolved the faster you can do it. The next most important to a fast, accurate, transparent decision is one that fits properly and it is not returned. In conclusion, fully integrated digital solutions with 3D virtual simulation of design concepts on mannequins that represent the target market of the company with digital fit models based on accurate input size data and not on body measurements that took place decades ago. As McCann (2015) very well describes it, the opportunity (the development of sustainable functionality) is beginning to present itself and the software company which develops the tools first and the brand who uses them to repair potential rifts in the fabric of their international operations, may well be favoured.

6

IoT/IoF

(Internet of Things / Internet of Fashion)

6

IoT / IoF

Internet of Things / Internet of Fashion

The Internet of Things, firstly coined by Kevin Ashton [Executive Director of the Auto-ID Center in Massachute Institute of Technology (MIT)], as the title of a presentation he made at P&G in 1999[35], is a technical revolution that is bringing us into a new ubiquitous connectivity, computing, and communication era (Ding et al, 2013). McKinsey (2015) defines “the Internet of Things” as sensors and actuators connected by networks to computing systems. Based on (Cecchinel et al, 2014), IoT is a notion that depends on interconnected physical objects. It creates a mesh of devices that are able to generate information. Sensors are around us like in cars, buildings, and smartphones that can collect data about our environment. IoT enables us to know things that need replacing, repairing or recalling.

Based on a range of IoT adoption rates, economic and demographic trends, and the likely evolution of technology over the next ten years, it has been estimated that the economic impact of IoT applications could be from $3.9 trillion to $11.1 trillion per year in 2025 with an estimation that factories are likely to have the greatest potential impact from IoT use—as much as $3.7 trillion per year (McKinsey, 2015).

The internet of things (IoT) is transforming everyday physical objects that surround us into an ecosystem of information that is rapidly changing the way we live our lives (Dassault Systemes, 2015). Any physical product can be more intelligent, more interactive, more trackable and more valuable by being connected via IoT.

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35 “I could be wrong, but I'm fairly sure the phrase ‘Internet of Things’ started life as the title of a presentation I made at Procter & Gamble (P&G) in 1999” (Ashton, K., 2009)

6.1 What IoT represents for TCF

All industries, including Fashion, are waiting for the IoT to make real quantifiable impact that can be quickly translated into positive ROI for the business, and equally a positive return for consumers (Harrop, 2016). This research project explored the impact of recent technology applications in the design and production of fashion products and the areas which are going to benefit most. The research has included several questions to interviewees who are executives in fashion companies or industry entrepreneurs. As it was expected, apart from one IoT expert, all the rest responses came from participants with limited experience in IoT. However, they strongly believe that IoT applications will have a profound effect on the way companies and individuals access information and ultimately make decisions. Furthermore, IoT will enhance and evolve our ability to manage and process information giving companies better visibility into their supply chain regardless if they are physically vertical (Birnbaum; Jouriles, Appendix 1).

If the Internet represents the democratization of information, IoT represents the democratization of big data. While there are already a few open source outlets of big data (data.gov, Google, cia.gov, amazon etc.); because of the means by which data is aggregated it can be very difficult to determine its quality and validity. However, it is believed that IoT will be a transformational trend in the short and long term. (Porter & Heppelmann, 2015) posits that "what is underway is perhaps the most substantial change in the manufacturing firm since the Second Industrial Revolution, more than a century ago". Microsoft's Global Thought Leader believes it too although he states that they are probably not thinking of the fashion industry (Tiffany, Appendix 1). The VP of Gerber Technology on the other hand, classifies IoT as the forth industrial revolution. In particular, he suggests the evolution as follows (Jouriles, Appendix 1):

1. Steam power makes mechanical production possible
2. Electric energy makes mass production possible
3. IT and computer technology allow for more manufacturing automation
4 Internet of Things makes networked manufacturing possible

An international Garment Industry Strategist (Birnmaum, Appendix 1), pinpoints some serious problems that will come to fruition such as:

- **Few laws regulating IoT and the internet in general**
- **Limited protection of individuals from governments, organizations, other people etc**
- **Security problems in transactions**

Barriers like these will be discussed as challenges in section 6.2.1. Furthermore, IoT will enhance and evolve our ability to manage and process information giving companies better visibility into their supply chain regardless if they are physically vertical (Birnbaum; Jouriles, Appendix 1) & (Fig.6.1a). If the Internet represents the democratization of information, IoT represents the democratization of big data (Fig.1b).

Figure 6.1a
Connected Apparel Products

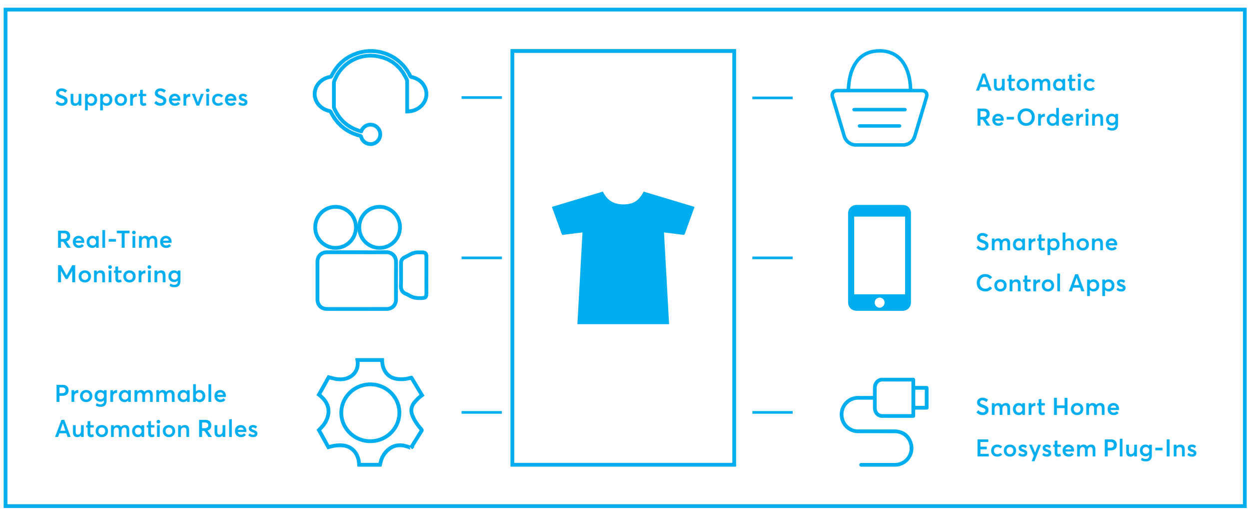
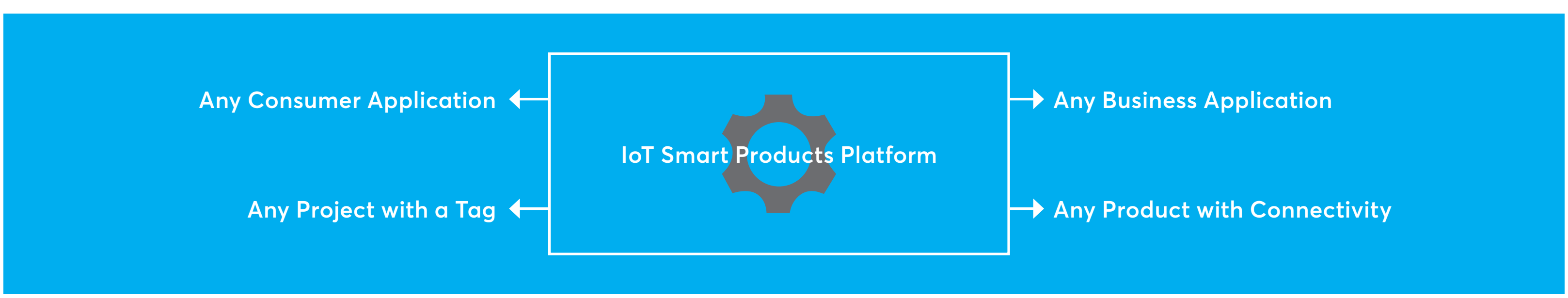


Figure 6.1b
Internet of things Connectivity



6.1.1 Cloud & "Big" Data

The notion of the Big data is related to the computer science since the earliest computing days. The data volume that goes beyond the processing capacity of the usual database and cannot be handled by traditional database techniques is called, "Big data." (Aly et al, 2015). Whereas Internet of Things (IoT) mainly focuses on how to enable general objects to see, hear, and smell the physical world for themselves, and make them connected to share the observations (Ding et al, 2013), a huge amount of raw data is collected on an ongoing basis and makes it essential to develop new techniques able to transform raw data into valuable knowledge. The collected Big data may not have any value unless analyzing, interpreting, and understanding it.

IoT will allow Big Data to be collected, aggregated and analysed, providing better predictive analytics. A result will be lower inventories and even possibly on-shoring of manufacturing to keep manufacturing as close to the customer as possible; the right product, at the right place, at the right price (Juriles, Appendix 1).

Other studies argue that the application technology of IoT will bring with it a whole new explosion of data that, if managed correctly, can be of enormous value to the contact centre and customer experience delivery. Contact centres will be able to gain more control of customer service by the Internet of Things providing them with new streams of information that is integrated into their existing infrastructure (Kosaraju, 2016). Primary research of this project also points to the same direction. Correctly managed data can also be an enormous value to the business and customer experience delivery. The value to customers can range from active service to aggregated performance, and sales analysis (Jouriles; Tiffany; Appendix 1).

The new product data is valuable by itself, yet its value increases exponentially when it is integrated with other data. Indeed, as we discussed in Chapter 2, section 2.1.6 VirtualTry on and in Chapter 4, section 4.6.4

Connected end-to-end data, having the intelligence and a large data set from technology like i.e Bodylabs provides essentially a better way to fit clothing, a better way to size up and size down a potential customer's bodyscanning. What is missing at the moment is the integration of these applications with PLM tools to provide feedback of how well the clothing of a company is fitting it's customer segments (Liao, Appendix 1). Capturing such insights is the domain of big data analytics, which blend mathematics, computer science and business techniques (Porter & Heppelmann, 2015)

Big data derived from in-store technologies can help drive content and promotions, as well as dynamic pricing, not to mention assist with inventory management by determining which products are in demand (Adobe, 2016).

To better understand the rich data generated by smart, connected products, companies are also beginning to deploy a tool called a "digital twin."—a 3D virtual-reality replica of a physical product (Porter & Heppelmann, 2015). In the fashion industry as this research argues, this digital twin is the virtual prototype which allows the company to visualise the status and condition of an apparel product that may be thousands of kilometres away, providing insights into how products can be better designed, manufactured, operated, and serviced.

The powerful new data available to companies, together with new configurations and capabilities of smart, connected products, is restructuring the traditional functions of business-sometimes radically. This transformation started with product value chain. As it spreads, functional boundaries are shifting, and new functions are being created (Porter & Heppelmann, 2015).

6.2 The Clothing Industry 4.0- IoF (Internet of fashion)

(Senanayake, 2015), made a prediction arguing that in the future, there will be many applications developed to be used on mobile devices, providing apparel companies as well as consumers the opportunity to design, develop, visualize, and purchase apparel products fast (see also section 2.4). The virtual representations will look real, with virtual collections, dressing rooms, show rooms, etc.

The technologies are becoming more affordable, so that the so-called complex, expensive technologies used by hightech industries such as aerospace, will be used for consumer products such as apparel. The new generation of consumers will not agree looking at a picture of an apparel product but will look for a virtual dressing room to experience virtual fitting before making a purchase decision. For this, the technological tools will become more available through the web and cloud-based applications on mobile devices.

(McKinsey, 2015) identified nine settings where IoT creates value. Our research singles out two of them: Retail Environments (Spaces where consumers engage in commerce) & Factories (Standardized production environments). Based on research and interviews, we believe that those are likely to have the greatest potential impact from IoT use. This thesis however focuses on the technology applications in the product development process. These applications along with modified hardware and operating systems embedded in the products, are series of layers known as a “technology stack” (Porter & Hepperlmann, 2014). Smart, connected products require that companies build an entirely new technology infrastructure, consisting of these layers. This technology enables not only rapid product development and operation but the collection, analysis, and sharing of the potentially huge amounts of longitudinal data generated inside and outside the products that has never been available before. Thus IoT has the potential to support Fashion Design, Development and procurement as well as manufacturing but the vast amount of data provided to fashion businesses by IoT aren’t still used effectively. We asked the participants if they expect a greater understanding of the value of this data, how to use it and make better decisions and how to pinpoint that data from sensors and connected technology is best utilised.

6.2.1 Challenges

The IoT offers several new prospects to the industry and end user in many application fields. The IoT needs theory, technology, architecture, and standards that join the virtual world and the real physical world in a merged outline. Some of the impediments to mass rollout of IoT are the following:

- **Energy Source**
- **Education**
- **Data collection, Protection**
- **Security and privacy issues**
- **Standards confusion**
- **Fragmented supplier base**
- **Affordability**
- **Intellectual property**
- **Availability of the network**

In Chapter 4 and more specifically in Section 4.6, we exploited that although fashion companies (in their aim to achieve sustainable competitive advantage) embrace best practices across the value chain, they rarely integrate data, solutions, resources and processes from end-to-end. Most IoT data collected are not used, and the data that are used are not fully exploited (McKinsey, 2016) due to:

- **Lack of understanding of the potential to use data**
- **Technical challenges including finding efficient ways to transmit and store data**
- **Analysing the data to derive actionable information**

Although most of the IoT applications are focusing in Retail at the moment, according to (Tiffany, Appendix 1) the explosion of data will affect not customer related things. Companies will have to invest in putting sensors and monitor the health of the manufacturing equipment first; long before start monitoring customer behaviour.

"Like in every technology revolution that comes along, we all think it is going to be this shiny scientific thing. The reality is that you look around and you are surrounded by old things. The transformation period is never smooth and it never happens like that; you go this rough, slow time, how much is this going to cost, how long will it take me to make back the money I invested in equipment for manufacturing (ROI). So, business leaders are all going to be thinking of all these things" (Tiffany, Appendix 1)

To make IoT data actionable in applications where human judgment is required, takes technical skills and an organization that is prepared to embrace data-driven decision making (Mckinsey, 2015). This statement, comes in total coincidence with what we have presented in Chapter 4, Section 4.5 (Challenges) on the full adaptation of Virtualization technology as an integral part of the fashion product development. It is evident that the fashion industry is undeniably behind in terms of integrating IoT with the fear that IoT will only lead to more data and not necessarily a more comprehensive analysis. However, there are optimistic views that real-time access to supply chain information from fashion companies, as well as insight into the way consumers actually use and interact with their products/creations will be a good motive for the industry to embrace the technology enabling the IoT (Birnbaum; Jouriles; Tiffany; Appendix 1).

6.2.2 Opportunities of IoF in the design, product development and manufacturing cycle

According to CEO of Cisco (Howarth, 2014) only 1% of the world's devices are connected today. This creates an obvious opportunity for those that want to connect all those devices but it's also a great opportunity for a number of new businesses to be created that can help industries derive value from all of the new data that will be available.

Product development processes will also need to accommodate more late-stage and post-purchase design changes quickly and efficiently (Porter & Heppelmann, 2014). Smart, connected products also call for product design principles that depart dramatically from tradition (Porter & Heppelmann, 2015).

In Chapter 2, Section 2.3, we identified that the implementation of Product Life-cycle Management (PLM) allows successful integration across the fashion enterprise: it is not just

Table 6.2.2 (bottom)
Analytics table by EDITED
Source:
https://edited.com/product/pricing/

a technology, but a strategic business approach that integrates people, processes, business systems and information (d'Avolio et al, 2015). Leading companies in return from investing in IoT can orchestrate and collaborate regarding changes in the product development process as opposed to reacting to problems. Moreover, trend data shared with merchandise planning solutions that can use smart analytics and algorithms to predict the next design trends and colours (Harrop, 2016). AI-assisted Design systems can help designers by making more accurate predictions of what designs will work and taking over some of the repetitive tasks. Fashion designers armed with AIs will be able to come up with radical new ideas, amplifying their creativity rather than replace it (Abnett, 2016). Data-driven technology companies like EDITED[36] and Stylumnia[37] provide solutions to help clothing brands to prepare the next seasons collections based on evaluation of consumer behaviour. Buyers and merchandisers use that information to address gaps in their own assortment, while designers use it to detect trends in their early stages and develop product accordingly (Table 6.2.2).

[36] https://edited.com/

[37] http://www.stylumia.com/

Price Points USD	7 For All Mankind 47,025	Diesel 207,152	G-Star 104,283	Levis's® 76,828
$0-20 21,537	324	7,548	2,029	11,636
$20-40 83,222	3,794	41,597	16,945	20,886
$40-60 71,569	5,345	33,891	17,809	14,524
$60-80 67,183	7,965	30,126	17,288	11,804
$80-100 46,722	8,025	19,920	12,516	6,261
$100-120 36,590	4,698	15,706	11,409	4,777
$120-140 26,398	3,024	12,727	8,347	4,300
$140-160 19,373	2,668	9,720	5,730	1,255
$160-180 12,574	2,116	6,797	3,343	318
$180-200 12,476	2,386	6,790	3,014	286
$200-220 7,378	1,478	4,001	1,698	201

Embedded computing sensors will not only be found in clothes. Manufacturing equipment capabilities go beyond the production of the physical product; for example, spreaders, cutters and sewing operations could all use IoT to communicate pertinent real-time information providing visibility across the entire product development process and supply chain (Jouriles, Appendix 1). According to (McKinsey, 2015), the major applications of IoT in factories are:

1. **Operations optimization**
2. **Predictive maintenance**
3. **Inventory optimisation**
4 **Health and safety**

Machines increasingly can be linked together in systems tracking feedback on status of products and even the health of the manufacturing equipment. Shop Floor Control Systems help to achieve real-time manufacturing visibility and control by removing traditional infrastructure requirements an adopting IoT technologies for the factory floor. These systems enhanced with tablets which can scan QR codes and feed real-time data into a production management system/ERP, operators can view files, such as PDF's, videos, images that are connected to the item scanned. Data feed also included real-time tracking of WIP and promote Lean or team based manufacturing with a team login versus individual (Simparel, 2016; Hanson, 2016).

Benefits for the consumer

IoT technology has the potential to drive down the costs of goods and services. By comparing usage patterns from smart, connected products, companies can gain a sharper picture of product use and provides much finer customer segmentation. Customers of companies that operate IoT systems, ultimately will be the ones to capture the most value in the form of convenience, lower prices, higher quality, better features, improved service and more attractive customised promotions.

Benefits for the companies

Companies that use IoT in novel ways to develop new business models or discover ways to monetize unique IoT data are likely to enjoy more sustainable benefits. To remain competitive, companies would need to master new ways of operating and learn to collaborate closely with technology and data vendors.

Although it all sounds promising and uniquely positioned to disrupt and transform the fashion supply-chain paradigm (Harrop, 2016), work still needs to be done in beacons and we need to be mindful or worried about the backlash from consumers;

"consumers may reject this. I think it is a dance we are doing with the consumers, a fine line that we don't want to cross over too far. It sure is exciting. IoT is the new Mega Trend; it is going to sweep through, it will be rough early on but I think the companies who see the future in this and have the capital to spend their money to update their equipment, they are going to be moving ahead" (Tiffany, Appendix 1)

6.2.3 Opportunities of IoF in retail

Currently, fashion brands and retailers work with a limited amount of data, to predict what products to order and when to discount or replenish them. If they predict wrong, the result is loss of income due to mark-downs, waste and popular items selling out. By analysing large amounts of data (i.e the browsing and shopping history of every single one of a fashion brand's online customers, as well as those of its competitors) AI and machine learning can tell a retailer how to align product drops to match demand, and even how to display products in a store to sell as many as possible (Abnett, 2016). Machine learning can also enable brands to finely personalise their offerings to each market, or even, each individual customer. Adobe, in a recent study presenting the Retail Stores of the Future (2016), pinpoint Personalisation as one of the key focus areas. Retailers can use solutions like interactive screens, beacons, geo-conquering and geo-fencing to deliver more personalised content based on customer's interactions, interests, and location.

Image 6.2.3
Examples of IoT in Retail
Source: McKinsey 2015, p.57

RFID chips embedded within products can track product engagement as customers touch and pick-up products. iBeacons as well, an advanced nation transmitter that can incorporate alerts for deals and accept mobile payments from customers, can provide big data analytics for businesses. Augmented reality with hand control will allow customers to perform iconic gestures. This development combines AR, hand tracking face recognition and the ability to work in virtual space.

- **Automated checkout**
- **Smart CRM**
- **Real-time in-store promotions**
- **Layout optimisation**
- **Inventory shrinkage prevention,**

are the largest applications in retail environments in potential economic impact of the IoT (Image 6.2.3).

As with other accelerated technologies as 3D virtual visualisation and 3D virtual prototyping thoroughly examined and posited in Chapters 3 & 4, adoption of the above applications remains uneven in the retail industry with larger chains usually leading the way. In order to make economically attractive the IoF, the RFID tags need to become so inexpensive to be used in every single item. Advance is needed in data analytics to take full advantage of the potential to combine IoT data with other data to provide all the prolonged benefits.

6.2.4 Scenarios / Cases for Clothes of the Future

With the IoT any physical product when connected can be:

- **more intelligent**
- **more interactive**
- **more trackable**
- **more valuable**

An initiative from two companies, Avery Dennison and IoT startup EVRYTHNG, will create 10 billion apparel and footwear products with unique digital identities and data profiles in the cloud over the next three years (Meyer, 2016; Wong, 2016).

Avery Dennison (a packaging and labelling company that puts label on products for brands like Nike, Adidas, Hugo Boss) and Evrythng (IoT platform backed by Cisco and Samsung) are collaborating to digitise world's biggest brands' products by giving each one a unique software identity that connects them to the web. Avery Dennison will attach special labels, sometimes including sensors, to clothes when they're manufactured which function as unique identifiers for each piece of clothing, and the data is stored in a platform developed by Evrythng. Those products from some of the world's biggest fashion and performance apparel and footwear brands will be able to:

- **Connect to smartphones to trigger applications and services**
- **Provide manufacturing history**
- **Generate real-time data for new applications and direct customer conversations**
- **Be tracked in real time from factory–to store–to home triggering alerts if they have been diverted or tampered with**
- **Participate in various after-sales loyalty schemes or recycling programs**

As it was presented in section 6.2.1, data privacy and security which for many researchers is the vulnerability of the internet of things, is a topic needed to be squared up to.

In sections 2.1.5 (BodyScanning) and 4.6.3 (Customized clothing for proper fit) we analysed how technologies like the one of BodyLabs will provide essentially a better way to fit clothing; a better way to size up and size down. Having the intelligence and a large data set from technology these kind of applications can integrate with PLM tools providing feed back of how well the clothing of a company is fitting it's customer segments. In the future, technology will be able to tell a customer's entering a store measurements down to his shoe size because of surveillance camera data (Liao, Appendix 1).

For many, the fashion industry remains in the past. The notion of "seasons", mass manufacturing, mass distribution of goods plus the lack of a new value system are only some of the obstacles preventing traditional fashion companies from evolving (Birnbaum, Appendix 1). The fashion industry as we know it today is over.

In no way does it respond to the needs and values of consumers. The IoT is here and all around us (Harrop, 2016). Virtual or augmented reality will fundamentally change the way we relate and communicate.

While the Internet of Things is certainly generating lots of interest and publicity, consumer adoption is not there yet. Forrester reports that only 7% of online adults in the US are using connected home devices, although, more than 50% are interested in using them (Doyle, 2016). It is apparent that the Internet of Things is changing, and the following years are going to be exciting for businesses, analytics and growth. The fashion industry and it's consumers need to understand and embrace these changes to capitalise on the benefits of the going interest in connected technology.

Furthermore, Business users of IoT technology will need to change their systems and organizations in order to make the most of the Internet of Things. They will need to invest in capabilities, culture, and processes as well as in technology. Businesses that fail to do so are likely to fall behind competitors that do. Smaller companies will need to find ways to obtain data on the scale required to compete with larger companies that will have access to sufficient data-in-house (McKinsey, 2015).

7

Conclusion and Future Work

7 Conclusion and Future Work

The study was set out to explore the effective integration of Digital Prototype in the product development process of the TCF industry, investigating the level of implementation of new digital technologies and especially 3D visualisation and virtualisation of a garment product comparing the enthusiasm, vision, scepticism, evangelism and restrained optimism between technology providers-vendors, entrepreneurs-independents, professional & experienced users and academics-researchers of clothing/fashion courses. Through personal interviews, the study has also sought to identify not only how these new technology solutions are being used in the industry today, or how advancements to the technologies behind them are likely to drive increased adoption and emergent opportunities in the future, but also the cultural changes in the managerial corporate level and their implementation in the product development process and in the academic new course structure that needs to be done, in order to support the implementation of the technology and its managerial support. A research that combines all parties involved in the clothing industry and not only the end users or the technology advancements themselves but the next generation of technology fashion experts who must adapt and adopt in the technology-led business of modern fashion and fill the gap between the industry's growing awareness of 3D solutions and those currently in education.

The construction of the questionnaire was build in a way to shed light on several vital questions concerning the technology of 3D prototyping in PD. The study sought to answer three of these questions:

1. **Will 3D prototyping technology conquer the Fashion & Clothing Industry?**
2. **Will 3D virtual prototyping become a mainstream tool or is it a wishful thinking?**
3. **What are the plans and vision of big corporations that have already implementing this new technology in their processes?**

The research proposes on the one hand that the traditional process of sample making has not changed but on the other hand fashion companies although using it, are facing many problems: time spent in developing and approving samples, lack of standardisation of software solutions, willingness to adopt new technology and the poor fit of clothing products are some of them. New software tools are equipped with 3D visualisation capabilities, and promise an enabled more creative, innovation-based workflow. Digital prototype is at the core of this change due to being part of the speed-to market pressure in fashion companies. All of the participants believe in the potential of 3D technology in the clothing industry with some being more optimistic than others. Trying to answer the question "With the use of 3D virtual technology, how the traditional method has been altered?" the research has shown that there are many different perceptions on the way the 3D prototyping technologies have changed (and to what extend) the traditional development process. However, the most interesting issue that came out of the research is that the industry (apart from being very slow in changing traditional methods) and especially those companies who have embraced 3D virtual as part of their development cycle, is that they experimented first with this technology starting from the development of the final garment trying to reduce samples. In the process, they piloted in the early stage of the concepts' design and presentation in order to enhance the creation phase.

Along with the enthusiasm comes scepticism. The category of academics state that in virtual fit technology a lot of things have been done but there is need for more before it is practical; at least in terms of the consumer. In terms of the manufacturers, now the technology is more affordable and the market is more competitive, along with a new generation of, confident in digital tools, designers, 3D virtual prototyping will be pushed to fit their business. 3D in fashion is evolving slowly and according to academics it will speed up, although it should and could have been introduced in every main institution more than a decade ago.

On the contrary it has been ignored and still is by many fashion courses run by non-technologists and non-industry facing or economics aware lecturers, and ineffectively developed by those inexperienced practitioners who focus on design only and are generally fearful of change. As it was analysed in section 4.4, the biggest barrier in the fashion industry that keeps the "wall of fear" solid and high is culture; change of culture and acceptance of 3D technology should start from the beginning-education and the next generation of fashion experts. A small number of schools have already started covering these areas. Apart from isolated examples, most of school tuition plans are not aligned and not all students learn about the new software systems and functions. Not even the professors have the same knowledge and mindset on that. Education on a new concept of apparel design in a 3D environment should be considered. When therefore, academic institutions open up to new courses involving PLM tools and 3D prototyping technologies, employing new tech savvy educational staff, meet with experts and companies and learn from their experience with technology, then the academic world can provide the fashion industry with the changed workforce needed to support the implementation of new technologies and unlock its full potential.

The entrepreneurs' and independents' point of view is that although the software is continuously improved, in a much faster rate than it ever was before, there are many challenges that still need to be taken care of; people in upper management to believe in the vision of new technology implementation in the product development process, invest or at least examine what it could mean for their development processes and lead "change teams" to a new way of designing, communicating and merchandising clothing products. Unless the business has the vision, takes the risk, the initiative to invest, profits in the long run aren't gained. Confidence must be passed on to all parties and staff involved; multidisciplinary collaboration for one collective goal: to maintain a competitive edge and to insert newness to the product range and at the same time improving the clothing industry.

Visual communication, especially with 3D prototypes may clarify complex issues between researchers from different disciplines, as mentioned above, and bring research outcomes to end-users. Big corporations, who have leapfrogged the proof-of-concept stage already and moved to 3D prototyping to accelerate whether the pace or the creative productivity of their design and development (Catto, 2015), have created teams with diverse design disciplines. From pattern makers, fashion designers, product designers, even 3D visual artists with experience in the film industry. Why? One of the reasons is because there are no experts in the market with the right skills. The study identified the new role of the fashion designer in the 3D creative environment and the needed skills trying to investigate “Who is going to be part of the 3D development of clothes in the future”. The outcomes were quite intriguing: The academics stated that the future role is not clearly defined and skills of the 3D user in the apparel industry do not exist yet, individuals also agreed that a new expert is needed, and vendors are inclined towards a combination of a new expert with pattern design skills. Future research could be contacted focusing specifically in the academic knowledge and needed skills of the 3D professional user and the provided curriculum of today’s academic courses.

3D is certainly gathering real momentum and, according to many participants in the research, not before time. Early adopters of the technology like Adidas, Nike, Underarmour, Target, Coach and many others who have already adopted 3D, have experimented for years with this new technology and are applying pressure on the vendors to produce solutions that work. According to 3D User experts, if the tools are going to be used in the industry then they need to solve problems that people have. The above mentioned “change teams” are pressured to deliver results. Some problems are still there, need solving and the managers cannot predict how long it will take to solve them. Internal integration with existing systems plays an important role in this.

Big corporations ask the vendor 3D solutions companies to share technology standards to enable cross platform design of a broad range of products. Almost all 3D vendors only cater to one product type, but each product type can share materials and other modeling characteristics using a truly open system approach; systems need to be truly open regardless of product type focus. Training also takes time and is very cost effective especially for smaller clothing companies. Higher education can help in solving this issue educating the students to design in 3D environment with new solutions, before graduating.

Vendors believe that it is easy to use 3D today but the companies who have already adopted 3D are challenging the claimed benefits of, reducing prototype development time, increasing experiment time, cost savings, lead-time reductions, sustainability, better collaboration to name a few. Thus, there is a need for an easier, more beautiful and more real solution and a push into-adoption. by the vendors.

3D User experts though, are more cautious in their enthusiasm. They see it coming but not in less than 5 years.

"I imagine if we're looking 5–10 years down the road more likely for a real industry change" (Asay, Appendix 1); "3D creation and visualisation is working, but it is something that is continuously evolving and improving" (Valentini, Appendix 1)

"..in the future you will see more and more images that now you use in collection books, collections presentations (images are 9/10 flat drawings), see that moving to 3D" (Sluiter, Appendix 1)

A limitation of this study was that the quantifying evaluation of 3D technology in terms of quality, development, time and cost, was provided by a selected group of diversity experts—based on the fact that the research relied on qualified data. The researched sample is quite small but future research could be conducted to measure the effectiveness of 3D technology in a quantified manner.

One thing is certain: this technology is not the future; it's actually now. It is a promising technology that vows to shake the clothing industry, by making the line between "reality" and "virtual" fade even more. It continues to evolve at an increasing pace and as the research has shown, overcoming the problems and facing industry's challenges can only release its full potential to help transform the whole product development process of clothing products and even more.

Sustainable business strategies need to be adopted in the TCF industry. This research has investigated how the industry can use the prolonged technology and at the same time reduce the use of resources and the generation of waste, seeking to fill the gap between new technology solutions like PLM, 3D visualisation or 3D prototyping and the reduction of the environmental footprint of this processes with and across supply chain partners. The current research is the first attempt to present a new fully integrated product development model, with 3D virtual simulation of design concepts on mannequins that represent the target market of a company with digital fit models on accurate input of size data. Combining technology and sustainability to create products that fit relies significantly on connected end-to-end data; valuable data in a virtual apparel product and in a physical one. In this study we examine how IoT (connecting design, development, sourcing and retail) networks physical objects and systems together, enabling them to exchange information and enhancing better process visibility and decision making throughout product development.

History has proved that the industry of clothing and the academic world in fashion has always been technology resistant. Fashion brands, clothing manufacturers and pattern makers were expressing the same scepticism, if not unwillingness, to embrace CAD systems when they were firstly introduced in the 80s. It took more than a decade for a pattern maker to develop a garment's pattern digitally from scratch. Even today, there are still small fashion companies who are not using it and struggle with endless paper sheets, unproductive paper cutting and other non-digital manual processes.

Regarding 3D prototyping and visualisation tools and their acceptance in the product development process, although all answers were very promising and accompanied with encouraged answers like "Absoslutely", "Definitely" & "Inevitably", the positive answer "yes", in most cases, was accompanied with restrictions. Efficient users who today have a full time job in developing designs and virtual garments in 3D environment, are so enthusiasts to state that it will happen in 1–2 years time.

We have mentioned above that most of the academic world as well as fashion companies and employees in those companies are reluctant to change and invest, feeling "attacked" when it comes to changing their daily life/tools they work with. However, the last years there is a wind of change; a breeze of a transformative TCF industry. Big corporations, leaders in technology adaptation, involved in 3D virtual prototyping for some time, can today, see some outcomes; a light at the end of the tunnel. For some, depending on the product and on the number of several departments within a corporation, the distance to the light might be longer than others. Still, they had a plan and a vision to bring on the challenge, see the future and realise their goal: to fully integrate the virtual prototype technology into their development processes. Adidas, Nike, Target, Under Armour, Walmart, VF Group, Coach, and many other brands, employ it as part of their strategy, trying to put an end-to-end process with 3D, generate it to as many users as it's feasible (some have more skills than others when it comes to using technology like this, big corporations have natural attrition with people retiring and moving, new coming-in "blood" will be exponential in the use of it).

Vendors have been telling for the last fifteen years that 3D prototyping is the future but only a few were as visionary as the software developers themselves. Independents believe it is not the future; it is now. If companies do not employ it seriously to a certain extend they may lose out.

The technology providers realise they have to make sure that the software and the products themselves are sound enough and provide the information that maybe the people using it aren't aware of.

"That way they can rely on it. It can kind of fill the gaps for them and be something that is supplement and helps and assists them in achieving their goals"

With technologies evolving year by year, quality gets better and acceptance increases towards an end-to-end vision that moves into a more productized, easier to use approach. New solutions move away from expert tools being hard to use, adapt and integrate to a seamless experience from product creation to consumer. Right now it's more a fragment of good ideas. Merging these into a seamless experience across industries will be the future. Early adopters like the previously mentioned brands, or the researched case studies presented in this thesis, are requesting improvements, have met some of their goals but still there is room for improvements and growth. Further research could be conducted to identify the current provided solutions by the vendor companies and the improvement needs by the early adopters of the technology.

The future TCF company, as envisioned by proficient users and experts of 3D prototyping and managers of digital creation teams is with all creatives on board using 3D tools and get their end-to-end processes whether it's design creation, store-merchadise, selling or consumer facing retail work. Acquiring 3D technology on such a scale is not cheap, talking about integrated vision with PLM etc. This study focuses mainly on the 3D technology, as one of the most important trend of the near future. PLM however, is the backbone of the development process and provides a seamless process, from the first draft to the store—a process which every fashion company can today customise. Additional research in the field of PLM will add to the understanding of all process elements; even expanding PLM practices to include recycling and more sustainable ways to do business or future required mobile applications to access PLM.

Investing (in a large scale) in technologies like these with the ability to unify information and break down the silos, only large corporations have the power to do it. Even when they do, fragmented landscape with many divisions, many stakeholders, many processes create obstacles to overcome. There is also a lot of work to be done in gradually improving the availability of the library of things people have access to, in improving the quality of the end result and gradually connecting the manufacturing technologies to the creation technologies too. There were participants who even visioned a not so much labor-force driven TCF industry but a lot of automatisation possibilities, holistic 3D workflow in the whole development phase with 1 or 2 physical spams just for a human feedback. That 3D file will be used not only internally in the business but for e-commerce also (externally). Furthermore, they expect a lot of automatisation with just a 3D file and right into production with a push of a button straight to an automatic cutter. "All real clothes might have their own 3D models" suggests Ryan Lee of Clo3D (Lee, Appendix 1). He visions a synchronisation between real-world and virtual-world.

Leading innovators in textiles and apparel develop revolutionary new technologies that accelerate and integrate virtual environment into clothing. As we have seen, effective integration of digital prototype with 3D virtual prototyping technology in the product development process of the TCF industry, requires vision, change, risk, investment, resources, transparency, collaboration, connectivity and constant improvement in technology and in people. The potential is huge. Whether 3D earns its stripes and the industry dives into the transformation current, it remains to be seen.

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Appendix

The content of the interviews is undisclosed and confidential and only the advisory and examination committees had access to it