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Virtual Product Development and Management Opportunities in Fashion Industry

Master of Science Thesis

Examiner: Professor Heikki Mattila

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ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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The fashion industry is one of the largest global industry and one of the most profitable industries in the world. With the current economic meltdown and capital flows changing course, the fashion industry is witnessing huge changes. Design, Product development and management tools and techniques are perhaps the main stream competitive factor in this industry because Conventional design, product development and management of textiles and fashion products is a long-stretching process taking often long time and consuming countless hours of work, material and energy in sampling, counter-sampling and sales-sampling, as well as preparing marketing material, i.e., photos, videos, etc. 3D tools already in the market make it possible to design and present products virtually without physical samples.

The purpose of this Master of Science thesis was to analyze the current situation of the fashion industry with regard to 3D technology and then to investigate which virtual software designing tools are available commercially. By studying fashion case companies, an analysis is given that how fashion companies are currently applying virtual techniques in their businesses around the globe. What is the selection criteria adopted by these fashion companies for the selection of software providers as there are many software providers in the market with almost similar virtual tools offerings. The different forms of support provided by the other organizations in implementing 3D are presented. Also by interviewing various key personnel related to virtual product design and development, i.e., company heads, managers, designers, etc the research presents the challenges, expectations and future developments regarding to virtual software's usage.

DEDICATION

To the four pillars of my life: God (ALLAH), my wife & son,

And my parents. Without you, my life would fall apart.

I might not know where the life's road will take me, but walking

With You, God (ALLAH), through this journey has given me strength.

Sobia & Hamza, you are everything for me, without your love and

Understanding I would not be able to make it.

Mom & Dad, you have given me so much, thanks for your faith in

Me, and for teaching me that I should always keep going.

I kept going and reached my first star.

We made it…

PREFACE

I am deeply indebted to my supervisor Dr. Heikki Mattila for accepting my thesis under his supervision, which created the opportunity for me to carry out this research at Tampere University of Technology with a scholarship stipend award from Finnish Textile Association (FINATEX). At the same time, I am forever grateful to him for all the hours so patiently invested with guidance, supervision, encouragement and support, and for the intellectual information which helped shape this research.

I am also grateful to my co-supervisor Milka Mustonen for her valuable advices, guidance, extensive discussions around my work and for her detailed and constructive comments for making me get a start with this research.

Special thank goes to Satu Mehtälä, Managing Director of the Finnish Textile Association (FINATEX) for awarding me a scholarship stipend to support my research work and also a special thanks to Anu Juppi also form FINATEX for providing me the help and guidelines for the scholarship award.

This thesis would not have been possible without the help, commitment and knowledge from the software providers, fashion case companies and third party organizations used in the thesis. Thanks to all of you, for your time and interviews were extremely valuable to me and it was profoundly inspiring to listen to your stories and feel the passion for the fashion industry going 3D. I truly hope that these companies and organizations can inspire others to pursue a 3D pathway but also get other practitioners in the fashion industry to see what opportunities that lie ahead to help more SMEs in implementing 3D. I hope the future brings you all continuous "3D success" and thanks again for allowing me to tell your story.

I would like to thank my wife for her personal support and great patience at all times and my son for making my every moment so meaningful. My expression of thanks and gratefulness will never be sufficient to acknowledge the incomparable love, care and support I am continuously receiving from my parents no matter where I am.

Muhammad Azhar Iqbal

Tampere, FINLAND
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LIST OF ABBREVIATIONS

Abbreviation	Full form
2D	Two-dimensional
3D	Three-dimensional
APGS	Automatic Pattern Generation System
CAD	Computer Aided Drawing
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
GUI	Graphical User Interface
PDCC	Productivity and Design Development Centre
PDS	Pattern Design System
PLM	Product Lifecycle Management
SME	Small Medium Enterprise
SRA	Strategic Research Agenda
SRM	System Response Matrix
T2L	True-To-Life
TaFf	Textile and Fashion Federation
TPC	Three-dimensional Pattern Concept
V.Gc	Virtual Garment center
XML	Extensible Markup Language

1 INTRODUCTION

1.1 Motivation

Fashion industry is one of the most profitable industries in the world. With the current economic meltdown and capital flows changing course, the fashion industry is witnessing huge changes [1]. Design, product development and management tools and techniques are perhaps the main stream competitive factor in this industry which operates in very fast moving, trend driven and rapidly changing markets. In the present times to stay successfully in business, the fashion industry globally requires evolutionary digital technology landscape, which can be implemented in the vast fields of product creation, marketing and sales, so time and cost can be reduced and also have access to multi channel marketing. All these benefits suggest that research into the possible use of virtualization systems in all aspects of this industry [2][3].

It is clear that which side the fashion industry is tending to move in the future, but it is not clear that which characteristics of virtual system are suitable for achieving which kind of opportunities in the fashion industry. There have been many researches in this regard, but still empirical research into the use of virtual prototyping for fashion industry is necessary. Therefore, there are opportunities within the fashion industry such as product development and management efficiency improvements (physical sample reductions, shortening time to market, sustainability regarding performance and quality, lowering service costs, suitability for all partners) that can be highlighted [4]. Furthermore, a study of the companies providing the virtual software tools should be done thoroughly, so it can be evaluated which softwares are available commercially in which regard in respect to product development and management within the fashion industry. The fashion companies already virtually applied in their business what challenges they are facing with 3D technology and if any other organizations are providing any support, they should be analyzed.

1.2 Background

Many previous and ongoing studies have taken place under the Euratex (the European Apparel and Textile confederation) strategic research agenda of the European technology platform for the future of textiles and clothing. This was one of the most recognized studies for the implementation of virtual prototyping in all sectors of fashion industry. There are several strategic research themes being researched in different parts of EU with many partner universities, institutions contributing for different projects in different fields under EURATEX vision for 2020. The following are main strategic research themes under strategic research agenda (SRA) developed in 2005, and then later modified with the passage of time and implementation of new projects. The main themes are: functional products for specific applications and usages, intelligent manufacturing and the smart value chain, new design and product life cycle concepts, and customization, personalization & consumer empowerment [5].

According to the Euratex annual report (2004) under ECS 6th framework program for R&D (FP6**)** approximately € 25 million targeting research projects for textile and clothing industry of EU were approved [5], alongside some smaller projects a main project was titled "LEAPFROG" (Leadership for European Apparel Production From Research along Original Guidelines). This was established to achieve virtual Garment 3D prototyping, innovative fabric preparation, textile-clothing value chain integration and automated / robotic garment manufacturing for fabrics handling and automatic garment components integration, it was successfully completed in 2009 [5][6][7]. According to the literature available in the Euratex annual report 2006 [5], during the 7th framework program (2007-2013) more than approximately €50 billion will been almost spent on textile-related research topics and other research projects. A part worth of €10.8 billion of this FP7 budget is agreed for 2013 for research and innovation for fashion and other fields according to European Commission report [8]. Some of the main projects which were based on the SRA of virtualization within the fashion industry specifically dealing with the research in the areas of virtual product development and management across the globe are summarized in Table 1.1 on the next page.

1.3 Research Objectives & Questions

The overarching aim of the study is to provide knowledge about which softwares are available commercially in which regard in respect to virtual product development and management opportunities within the fashion industry.

To achieve this aim, the following objectives have been set:

- *Provide an exploratory overview of current situation of the fashion industry regarding product development and management.*
- *Understanding current technologies available to which extent.*
- *Understand and analyze the role of case organizations in regard to the usage of virtual tools and also highlighting associated challenges.*
- *Interviewing some of the leading company heads involved in virtual product development opportunities.*
- *Other organizations support in implementing 3D technology*.

Table 1.1: *List of some of the main completed and ongoing projects related to virtualization in product development and management in fashion industry [4][5][7][9].*

Project title	Objective	Cost	Coordination	Status / Time
LEAPFROG IP	Developing and implementation of new ways of optimal fabric preparation for clothing production, automated garment manufacture, virtual garment prototyping, supply chain integration and mass customization.	€ 23 m	Euratex and 34 partners	2005-2009 (completed)
FDD (Future Fashion Design)	Development of production and business virtual workflow, which will represent the whole development process virtually for textile and clothing companies.	€ 2.5 m	Fraunhofer-IGD and 5 partner organizations	1.10.2011 (continued - 36 months)
PROsumer.Net	Bring five European textile and clothing industry platforms under one domain. Based on the research agenda for products for specific applications, intelligent manufacturing, New design and product life cycles, and Personalization and consumer empowerment.	-	Euratex and 9 partners	1.6.2011-5.2013
Fashionable	Providing European fashion industry new technology means that will provide the gateway to co-design and the sustainable manufacture of fully personalized products.	€ 5m	Caprara GIUSEPPE, INSTITUTO DE BIOMECANICA DE VALENCIA / SPAIN	1.11.2011 -31.10.2014 (36 months)

The research questions that reflect these objectives are:

RQ1: What virtual product design, product development and management opportunities there are in the fashion industry?

- What is the situation at the moment in the fashion value network in respect to virtual product development and management?
- What virtual product design solutions and techniques (CAD) are available in the market?
- Are the CAD systems provided by various companies identical or not?

RQ2: How fashion companies are currently applying virtual techniques in their businesses around the globe and what are the selection criteria for these tools, what challenges they are facing?

***RQ3*:** How can third party organizations be helpful in making the fashion industry going forward towards 3D?

1.4 Research Scope & Limitations

The research is industry-specific and was performed with three main goals in mind. The primary aim of this research project is to create know how among textile fashion companies and other members of fashion industry about the available virtual tools for product design, development and management around the globe and secondly to study some of the fashion companies which are using these tools, how these tools are selected and what are the challenges being faced by using these tools and how they can be overcome. Thirdly what other organizational support is available for implementing 3D technology in the fashion industry.

The selected case companies have demonstrated significant attention and devotion to usage of virtual product development and management techniques in their respective fields which in this case focuses. In this project the vision is provided for fashion companies about extraordinary uses and applications of these virtual tools to get the competitive advantage in the fashion market. This study will help the designers and companies who are not using virtual product development techniques to change their way of thinking and develop new products with physical sample reductions, shortening time to market, sustainability regarding performance and quality, lowering service costs, and suitability for all partners [4].

Only a few limitations are recognized within this research. Firstly, the limits exist on the information collected and the risk of misinterpretation because of usage of secondary sources. Secondly, some companies have limited information regarding virtual product development and management techniques on their websites and also want to share limited amount of 3D information, as it is the latest technology in the fashion industry.

1.5 Outline

This research is structured into the following chapters:

Chapter 1 outlines the research motivation, background, poses the research questions & objectives and provides details on the research scope and limitations.

Chapter 2 provides details on the research design and as well the data collection and chosen methodology.

Chapter 3 explains and analyses the literature available in the theoretical context of product design, development and management opportunities in the fashion industry.

Chapter 4 starts by introducing virtual technologies and highlighting the current virtual technologies being used in the fashion industry. Further on it explains what 3D virtual technology is and how it all works by briefly discussing the commercially available 3D CAD systems based on their working procedure to create 3D designs. It also presents the impacts of 3D technology alongside concept-to-shelf.

Chapter 5 presents the available virtual tools for product design, development and management in fashion industry by categorizing them with respect to their applications.

Chapter 6 provides the case study of the companies which are using different virtual tools around the globe. This chapter presents what is the selection criterion for 3D tools and what challenges and difficulties these companies are facing. It also gives an overview of the organization supporting the fashion industry going forward to 3D.

Chapter 7 aims to highlight some of the essential elements regarding 3D virtual technology, derived from the interviews, software providers, research institutes and also internet sources.

Chapter 8 provides an analysis of the information collected from literature analysis, available virtual tools, case studies, interviews, third party organizations and internet.

Chapter 9 concludes the thesis with a brief summary of the work and its outcomes. It also highlights some areas of further research work as recommendation.

2 METHODOLOGY

This chapter of methodology will show the process of gathering relevant information and models, how they are used and analyzed. As criticized by Hathaway [10], how researchers make decisions with very ease while choosing the research method, which will provide the needed information without paying attention to the assumptions that underline the research methods. So this methodology chapter is used to describe where and how to get data. Hart [11] defines methodology as *”A system of methods and rules to facilitate the collection and analysis of data. It provides the starting point for choosing an approach made up of theories, ideas, concepts and definitions of the topic; therefore the basis of a critical activity consisting of making choices about the nature and character of the social world (assumptions). This should not to be confused with techniques of research, the application of methodology*”. Therefore it can be said that the chapter of methodology is done to create deep knowledge and trustworthiness of the thesis. This involves different sections where the framework of the thesis is described and motivated.

2.1 Research Approaches

According to Creswell [12] there are many ways and means to construct the research approach, the most important of these emphases on the nature of the research topic. Being critical in the decision making process is very important as every decision which is made is going to be the base or foundation of the next one. Discussion regarding the different choices of inductive versus deductive and qualitative versus quantitative research approach is presented in the next section.

2.1.1 Deductive versus Inductive research

The topic on which there is already some research done and has wealthy data available from different sources, i.e., primary, secondary etc, deductive approach is better to use and the topic on which rarely there is any data available the inductive approach is used for this type of topic. As my topic is relatively new but there is reasonable amount of data available also from general to more specific analysis is to be done so deductive research approach will be used in this regard [12]. Deductive research approach is used by starting to read the existing theories available on product development and management opportunities in the fashion industry and then going into more specific theories and research studies what others have done related to the virtual product development in fashion industry [13]. Figure 2.1 outlines the steps involved with a deductive approach inducted for research.

***Figure 2.1:** Deductive research approach [13]*

2.1.2 Quantitative versus Qualitative research

The next step in the research approach is to decide the most suitable method to get the best outcome of the research investigation. According to Saunders, Lewis and Thornhill [12], there are two difference approaches, qualitative and quantitative. The thesis should be designed out of a qualitative or a quantitative research characteristic, this to make a paradigm or frame work that can be said as the basic system which will guide the investigation for how to collect and analyze the relevant outcome of the research.

Quantitative research techniques are used for the data mostly, which is present in the raw form, for example the research taken involves data range from simple counts such as frequencies to more complex data e.g., test scores, rental costs or some prices so this data will be needed to quantify [12]. According to Blaxter, Hughes and Tight [14], quantitative research is the collection of data in the numeric form, while qualitative research is more concern with the collection and analyzing of data in many forms, mainly non numeric as possible. It explores in detail as possible the data that is available in the form of being interesting and illuminating, which focuses on achieving the 'depth' rather than 'breadth'. Saunders, Lewis and Thornhill motioned in [12] that qualitative research technique refers to all non numeric data or the data, which have not been quantified and it can be the part of all type of research strategies. It can be said that qualitative research creates a deeper and wider knowledge as it allows developing theory from the data.

On the bases of the previous discussion, a qualitative research technique is most suitable for this thesis in the extent of the nature of purpose that is going to be investigated. This thesis is going to be constructed on mostly theories available regarding product development and management opportunities in the fashion industry, and also case companies will be studied in this regard as well. One to one, telephonic or emailed interviews of professionals using the tools of virtualization will be also conducted.

2.2 Research Design

According to Robson [12], collecting and analyzing in order to turn the research questions into a research project, research design is important for the thesis. Furthermore, the research questions which have been selected provide the base for choosing the research strategies, choices for collecting techniques. The research questions provide help to set the analyzing procedures for the collected data, and also give an opportunity to set a time frame for the whole research project. According to Saunders, Lewis and Thornhill [12], there are three classified research design methods: *explorative*, *descriptive* and/ or *explanatory design*.

Exploratory research design is a technique used to do pre-study and then to get deep knowledge of the problem by asking questions and to analyze phenomenon in a new light [12]. Further Saunders, Lewis and Thornhill, highlight that this design method normally relies on secondary research, such as reviewing available literature and data, also qualitative approaches such as interviewing experts in the research area is done to get a deeper knowledge [12]. The second method descriptive research is mostly used for statistical research, describing data and different characteristics about a specific population, conducting surveys and developmental studies which tend to change with the period of time [15]. Thirdly, the explanatory design method is used to make a relationship between variables [12].

Above mentioned three designs were carefully evaluated that which design suite this thesis in regard to the relevance and usefulness of the results. Since, this thesis is going to investigate relatively new technology in the fashion industry, thus the subject does not contain a lot of direct information available on virtual product development techniques being used in fashion industries. Therefore, an exploratory research design is going to be used for this investigation with case study research strategy as there will be several case companies that will be studied in this regard. Exploratory method will initially focuses on broad scale topic of product development within fashion industry by literature review, and later it will progressively become narrow to study the implementation of virtualization in the product development techniques in the fashion industry respectively by interviewing experts and managers using these techniques [12].

This thesis will proceed by selection of different research approaches, strategies and methods that can be summarized in the Figure 2.2 on the next page.

2.3 Data Collection

The process for collecting the data is divided into three categories: a) background and theory, b) case selection and c) interviews.

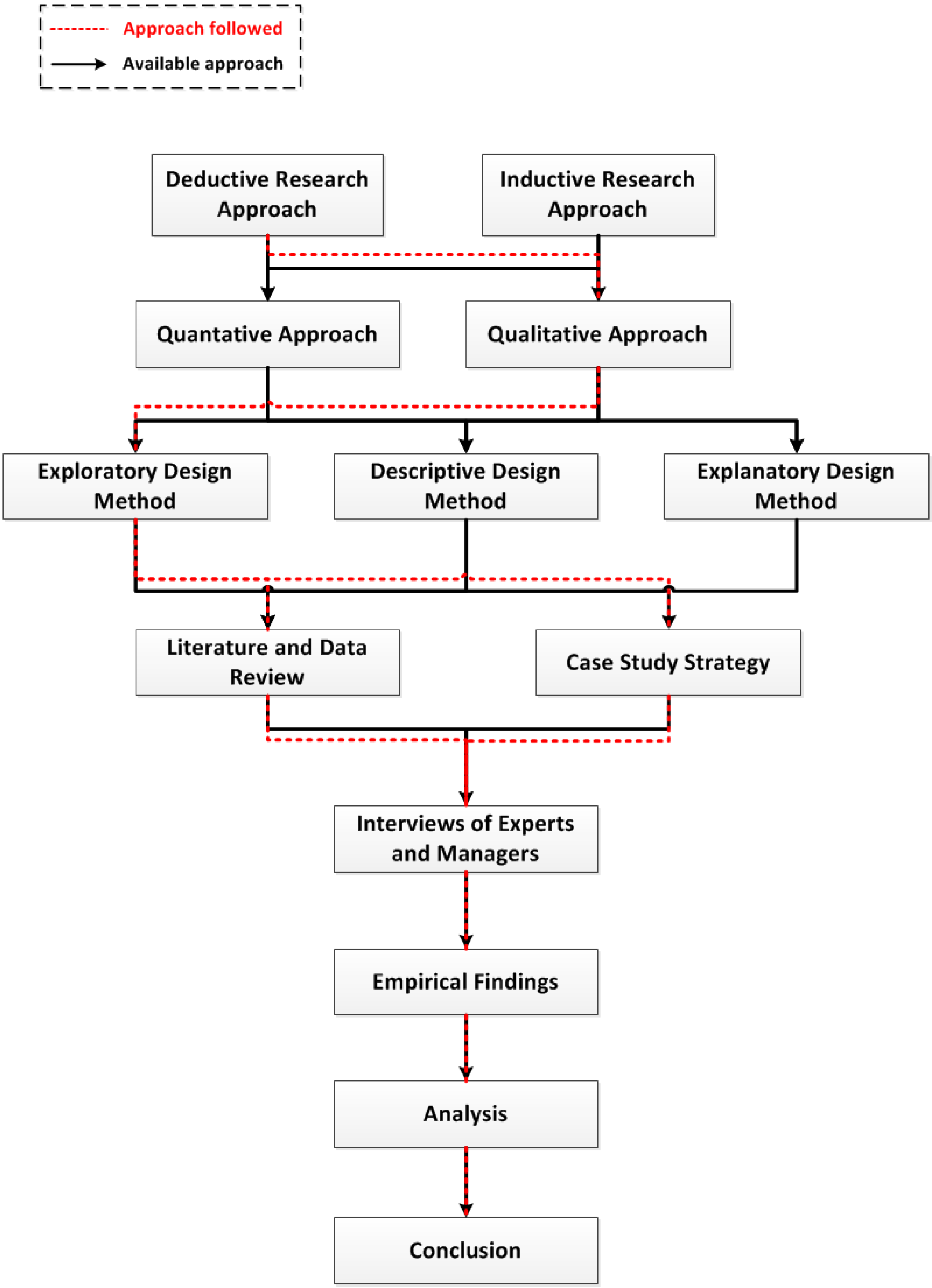

Figure 2.2: *Thesis methodology framework*

Background and Theory

This literature review is very important section for a research project as stated by Gill and Johnson [12], it provides required awareness of the current state of knowledge in ones research area, its limitations and how the research will fit in this wider context. For this section, the first step began with a literature review of reports, academic papers from international peer-review journals, books, thesis, internet, and other reliable primary and secondary data sources to gain a deeper understanding of the fashion industry and its practices with virtual product development issues. This literature review provided an overview of the exiting knowledge in the field of virtual product development and management opportunities within the fashion industry respectively. More specifically, this literature review provided a guideline to create a difference from other peoples research work related to the area of virtual product development and management opportunities in fashion industry, and thus helped to map and asses the existing intellectual territory [12].

Case Selection

The focus on virtualization in the fashion industry is because textile and fashion industry has been a pioneer in several transitions and product design, and fashion industries have been trendsetters. According to Heikki Mattila, virtual modeling of textiles is difficult and challenging, due to which the fashion industry is slow to catch on, but still there are a lot of developments made in this area as this is the future of fashion industry; besides many other advantages mainly, it saves time and material [16].

The case companies' selection is based on the interest and usage of virtual tools in product development and management opportunities by the companies, and to which extent they are being implemented. Common for all companies is that they are using some kind of virtual product development and management techniques within the company. By selecting the following companies, there is a possibility of providing a larger overview of the virtual tools being implemented in the product development and management departments in the fashion industry around the globe.

1) Adidas
2) Comercializadora Arush
3) ICICLE
4) Delta Galil

Additionally, other organizations for instance research institutions, textile associations, which providing support to the fashion companies regarding 3D technology were chosen due to their specific target to assist fashion industry in implementing 3D technology. It should be noted that there are many organizations which are providing support to the fashion industry to go forward towards 3D. By selecting the following organizations, a highlight of their different support for the fashion industry to go forward towards 3D is explained briefly in Section 6.2.

1) MIRALab, University Of Geneva, Switzerland
2) CAE Laboratory, Technical University Of Dresden, Germany
3) Council of Textile and Fashion Industries of Australia (TFIA)
4) Productivity and Design Development Centre (PDDC) & Virtual Garment Centre (V.Gc), Singapore

Interviews

The data was collected by semi-structured interviews, termed as qualitative research interviews [12], and interviews were conducted either by personal meeting, telephone or in some cases the questions were asked through email and responded through emails. Owners, managers, team leaders or other employees related to product development and management department were interviewed. The name of interviewees, interview question asked and other related information can be seen in Appendix A and Appendix B.

2.4 Intended Audience

The targeted group which will have large interests and relevance in the outcome of this thesis will be practitioners of product development virtual techniques with in the fashion industry, and beside the fashion industry it will be providing positive know how for the virtual software and system providers. It will also provide a knowhow and guidance for the academies and other organizations who are related to the studies and research of virtual tools for the product development and management processes for the fashion industry that how the fashion industry should be supported for going 3D.

3 LITERATURE ANALYSES

The aim of this chapter is to provide a literature overview of the practical background of the global fashion industry with particular reference to product designing, secondly to highlight that how fashion industry have been dealing with the concept of product development and management across the globe. Afterwards, literature overview on the changing environment of the fashion industry with a focus on product creation is presented.

3.1 Practical Overview of the Fashion Industry

A brief overview of the sector is given to ground the current research in its current and historical context from a product development and management perspective. The fashion industry defines an industry sector that is unique and global in character [17]. According to Allwood et al. 2006, DEFRA 2010, MISTRA 2010 [18], the importance of fashion industry in several countries can be judged by the percentage of world exports and employment opportunities provided by the clothing and textile sector. This sector has 7% of world exports, and it provides job opportunities for more than 20 million people around the globe. Barnard (1996) stated that “fashion and clothing may be the most significant ways in which social relations between people are constructed, experienced and understood” [19]. Similarly, Allwood et al discussed in [18] that fashion is about both function and aesthetics i.e., we wear cloths to meet physical and functional needs, adhere to social norms, demonstrate power and indicate group relationships. As stated by Priest [18], often fashion industry is regarded as coinciding with the apparel sector that indeed is its main component.

Further Brun et al, 2008 [18] argue that fashion is actually a cross sector concept, clothing industry is mainly applicable to this, but it can be extended to companies operating in other sectors, such as shoes, accessories, jewellery and also leather goods. Therefore, by the dimensions of product, brand and retail channel, a complete overview of the fashion industry can be captured. Fashion is a business and although some only see if as a superficial community filled with models and avant-garde designers, but there is a whole lot more to it. By breaking down the industry, it is apparent that a lot of hard work goes into making the fashion world go round.

The Table 3.1 on the next page provides a list of the fashion industry sectors with a brief explanation that what functions are performed in the particular sector.

Table 3.1: *Fashion industry sectors and functions [20]*

Sectors	Functions
Primary	Fiber / textile development Design Dye / print / finish conversion
Secondary	Design Production / manufacturing Sales / marketing
Retail	Buying / merchandising Management Sale promotion / fashion direction
Auxiliary	Advertising / publicity Buying offices Fashion publications Trade associations

Since this thesis has a focus on the concept of virtual product development and management opportunities in fashion industry, therefore only the secondary sector of the fashion industry and its functions are considered while dealing with only the apparel sector of the fashion industry. The overview of the apparel sector of the fashion industry is analyzed in the following section.

3.2 Apparel Sector

Textile and apparel industry is one of the earliest industries embedded in the global value chain. The output and export is among the largest industries in the world [21]. According to ZX Guo et al [22], apparel industry is one of the most important economic sectors and it has very importance in daily life and global economics as it produces what people wear. In his book [23] Richard M. Jones writes, “The textile-apparel pipeline is a series of interrelated activities which originates with the manufacture of fiber and culminates in the delivery of a product into the hands of the consumer”.

The manufacturers of textile products can be divided into three segments: apparel, home textile and industry/ technical textile. From these three segments, apparel sector is leading the global production ratio from the other two manufacturing segments of the textile industry. Apparel is being produced by a global production ratio of 43.5%, while home textile and industrial & technical textile are produced with a ratio of 33% and 23.5% respectively [24].

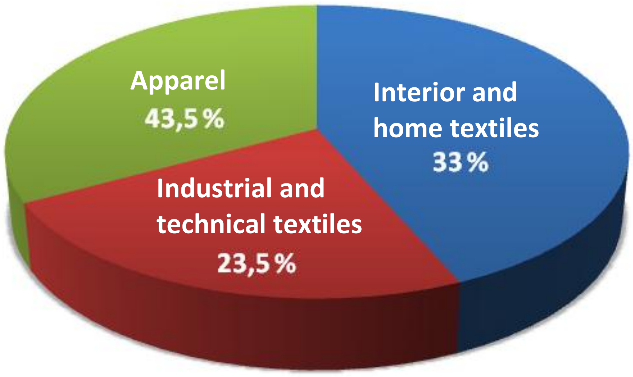

Figure 3.1: *The ratio of global textile production [24]*

The apparel industry is involved in the designing and manufacturing of clothing and other accessories and then providing them to the consumers [25]. It is also involved in producing clothing for the infants. Apparel industry is a big part of the fashion industry, so in order to keep up with the competitors and to continue the efficiency of the productions, this industry modernize the technology and products in a timely fashion manner [21]. Despite advances in technology and the work practices, still this industry is labor intensive. The industry increasingly out sources its production work to foreign suppliers in order to take advantages of low labor costs. Therefore most of the apparel manufacturers are performing only the role of entrepreneurial by providing the functions such as buying row materials, designing cloths and preparing samples, arranging for the production and distribution of the apparel and then marketing of the finished goods [25].

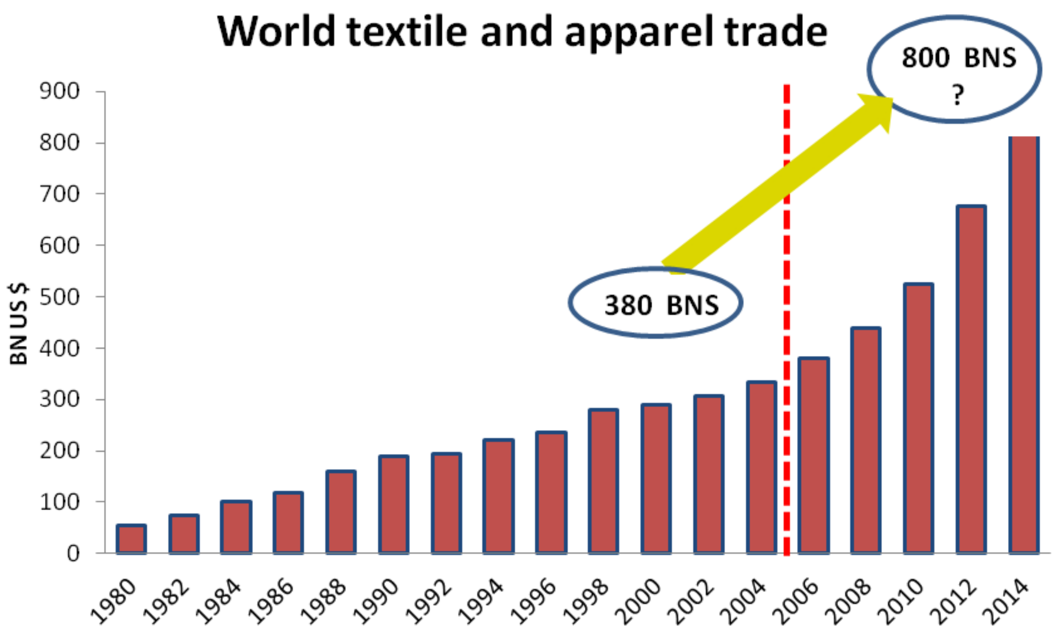

Figure 3.2: *The global textile and apparel scenario [24]*

Whatever labels a company owns, there will always be competition in the apparel industry. Brands compete for not only customers, but want to have prime display areas in department stores, which is extremely important for selling clothing. According to statistics, the global textile market was worth of more than $400 billion in 2005. In a more liberalized environment, the industry is facing competition as well as opportunities. It is predicted that global textile production will grow up to 50 % by 2014 [24][23]. The apparel manufacturing industry is modernizing in a very fast and rapid manner, because the growing international competition has made it necessary for the companies to invest in automation and information technologies. The advancements in computers and computer controlled equipment have significant importance in apparel industry as it provides help in many functions such as design and pattern making [25].

3.3 Processes involved for developing apparel products

Apparel design, manufacturing and retailing are the three processes that are involved in developing an apparel product from concept to consumer. According to ZX Guo et al [22], these three processes are the most important integral part of the apparel industry. According to the market needs and trends, first the designers create styles for a collection. There are four different steps involved in the apparel design process: design initiation, design concept, the decision making process and technical design. The second process is the apparel manufacturing that can be said as the process by which apparels products are made by following the guidelines of the design process, and then distributing them to the retailers. This process usually involves the steps of cutting, sewing, finishing, packing and distribution. The third and final process of developing apparel products is apparel retailing. In this process, the retailers deliver final apparel products to the consumers, and it can be considered as a link between the apparel manufacturing and the end consumer [22].

The processes which are involved in the development of apparel, starting from concept to consumer can be seen in Figure 3.3 on the next page. It also highlights that how these processes are interconnected to each other.

The first process of apparel industry creates new styles, and for the creation of new styles there are various decision making problems such as the selection of an apparel computer-aided design (CAD) system, determination of design elements e.g., fabric and color, pattern for the design and garment evaluation [22]. Since, the research is focusing on the product design, development and management opportunities, therefore the first process of the apparel industry will be analyzed in the next section.

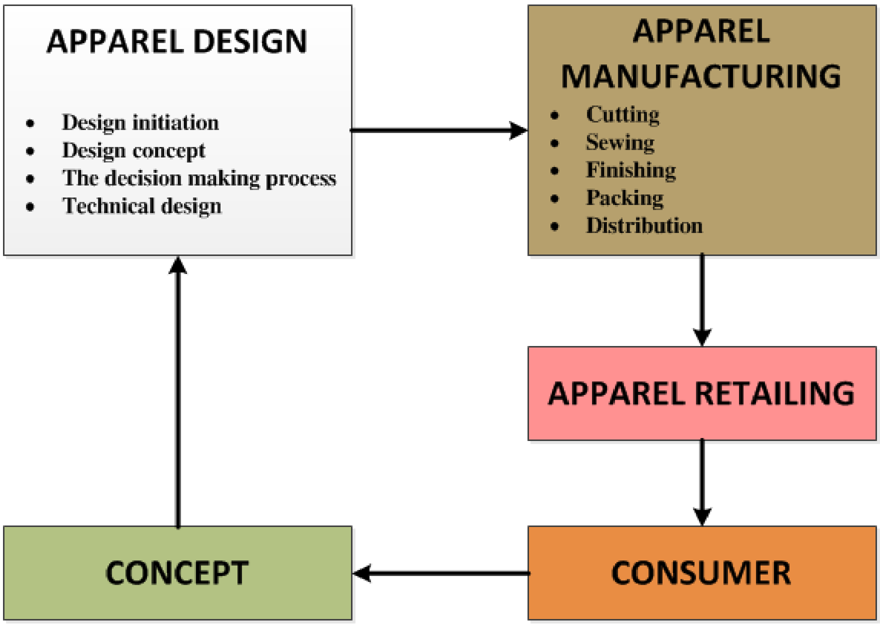

Figure 3.3: *Processes for developing apparel products [22]*

3.4 Traditional Apparel Design Process in Fashion Product Development

According to analyses of Rothwell [26], design has been identified as a significant factor in commercial success. Design is considered as of a range of non-price factors and it plays an important role in the competitiveness of manufacturing goods. The fashion industry is a highly competitive and design led industry, therefore textile designers face a considerable continuous pressure to produce new styles and designs or at least it is an essential requirement from them to imitate the styles and designs of competitors. Close following of market trends in design enables to achieve rewards as the industry is becoming more and more fashion led [26].

Fashion designers are the artists of the fashion industry. They are the one who create ideas for a range of different products including coats, suits, dresses, hats, and underwears [25]. A rigorous and deep involvement is required in order to develop and formulate a design, as in most of the cases this follows different process. The design process should be taken into consideration as course of action that would make the reaching of goal very much easier and in a simple way. According to Subhashree Sarkar [27], design can be defined as to express an idea in a form or to conceive the idea for some artifact or system. It also gives a meaning of reaching the goal with constraints. The goal refers to what will be the design used for and who will be the end user. The material and platform to be used in design process can be termed as constraints. The creation of a design which is aesthetic, creative and innovative at the same time is a very challenging job for the designers.

However the outcome is highly enhanced, if the designer is gifted with artistic talent and creativity. In spite of every individual having his/her own methodology for approaching the problem, designer or group of designers develop a specific format which guide them in making their task much easier and simpler. This method can be modified with time to time in order to improve and develop it for the best of purposes [27]. There are some factors which should be dealt with even before beginning the design work.

Some of these may be:

- **Identify the target market –** On the basis of gender, age, social and economical segment the market that the firm is dealing with should be segregated in order to satisfy each market segment, which has deferent requirements and expectations from the design and it can be successful.

- **Maintaining an identity for the brand –** As every company has a specific identity and caters to a particular client. Furthermore, the price ranges are also fixed since they carter to specific target market. All this has to more or less remain constant in order to maintain the company brand image [27] e.g., for outerwear garments virtual product development, LECTRA offers a software system called Modaris 3D fit, Assyst offers Vidya, Browzwear offers V-stitcher and similarly Optitex offers PDS Version 10/ Runaway. Their target market is outerwear producers which have companies like Hugo Boss AG, ESPRIT and S.Oliver etc [28].

The design process can be very complicated, but a very basic form may contain the stages showed in apparel design section of Figure 3.3. These stages may be treated as a separate unit or they might overlap each other. It is the designer who decides on these matters of using the process in what manner.

The stages involved in the basic design process can be summarized as follows:

3.4.1 Design Initiation

Proper research and planning is very important before starting a small or big project. A time frame is planned for the design by keeping in mind the nature and different stages that have to come across during the design process. During the design initiation process, the designer contacts with the clients in order to understand their preferences and needs. According to this information, the designer can conduct research that can comprise of an adequate study of the current fashion trends and forecast in order to develop the design [27].

3.4.2 Design Concept

The design concept is most important part of the design process. This part is the starting point where the ideas are started to generate, and the basic shape of the design is conceptualized. The design ideas or concepts might spring upon a designer at any moment of time, but it should be kept in mind that the ideas are according to the requirements or matching the market trends [27]. According to Tom Osborne [29], sometime designers need to get bunch of ideas in a short amount of time, and it is sometime not easy for one person alone. Therefore, team design benefits in this situation as collaboration is the key whether it is collectively or individually within a working group of people. It is argued by Keith Dickson et al [26] that design is not an isolated activity, but it feeds on constant interactions within and outside the design organization.

3.4.3 The decision making process or form

In the fashion industry this is the stage where sampling of design is initiated. This is the stage where the actual work on design is initiated, the physical structure, shape etc is determined, and the ideas and concepts are converted to form and shape [27].

3.4.4 Two dimensional technical design

The technical design in the traditional 2D to 3D way of designing the garments is based on designing patterns, and the patterns can be either imported from CAD systems or they can be manually created. Mostly in the garment production processes the patterns are initially designed and then cut in 2D space. Later, they are placed around a virtual mannequin in 3D space, and then sewing is done to make a complete garment. After which the garment is simulated in a virtual environment according to the physical and mechanical properties of the fabric. There are two main components which influence the visual appearance of the real or virtual garment. The first is the shape of the 3D garment that is determined by the 2D pattern, and the second is the material of the fabric used whose behavior is influenced by its physical and mechanical properties [30]. The following steps are involved in the technical design creation of garments in traditional 2D to 3D methods.

Pattern Design

Creating a 2D pattern is a precise handiwork. According to the pattern construction rules a flat pattern is drawn by the skilled experts by keeping the desired 3D shape in mind. The two-dimensional description of the 3D garment can be obtained in many ways, but the most traditional method is done by using a ruler and pencil on paper.

Digitalization

In order to use traditionally constructed 2D paper pattern for 3D application, it needs to be digitized on a digitalization board.

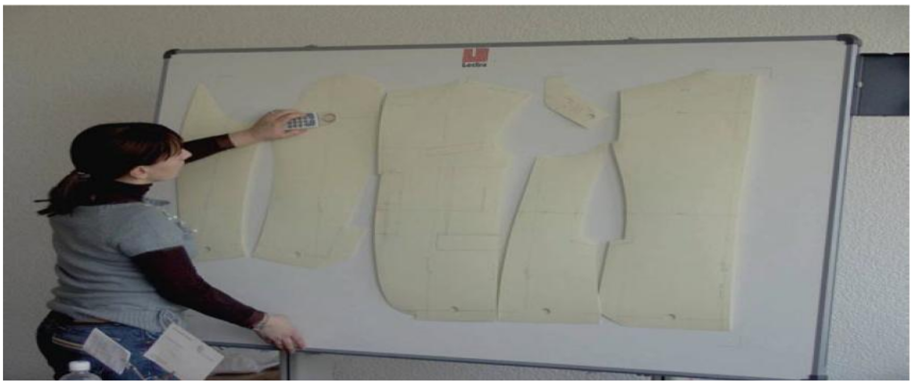

Figure 3.4: *2D pattern digitalization process [30]*

As shown in Figure 3.4 for the purpose of digitalization, the paper pattern is fixed on the board. By using a special mouse, the outlines and the construction lines of the 2D pattern are traced subsequently. Different points and markers are created by using different buttons of the special mouse. By this method, the shapes of the single pattern pieces are copied to the CAD Software and the 2D pattern is edited as an electrical pattern. It is then exported to the 3D application (Figure 3.6) [30].

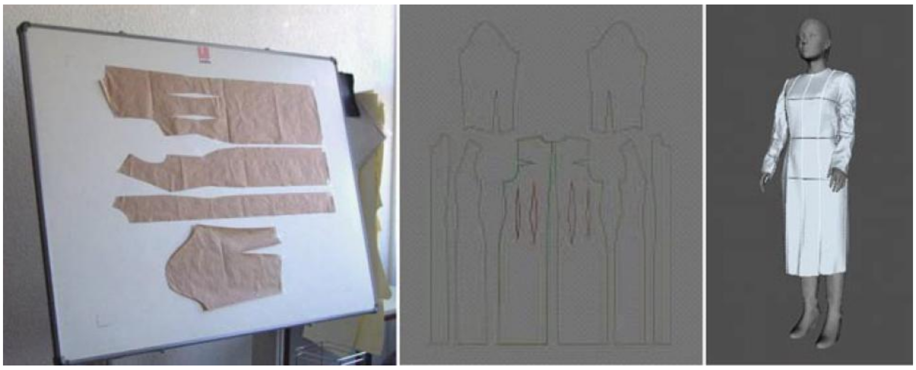

Figure 3.5: *Digitalization process: from the paper pattern on the left, to the digitized pattern in the centre and the virtual dress on the right [30]*

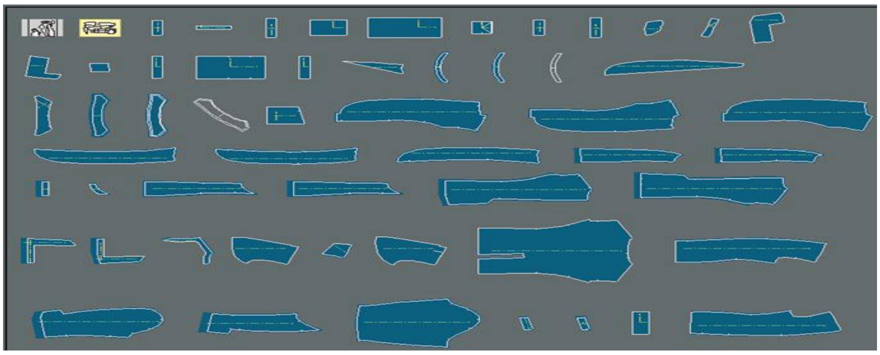

Figure 3.6: *2D pattern inside the CAD software [30]*

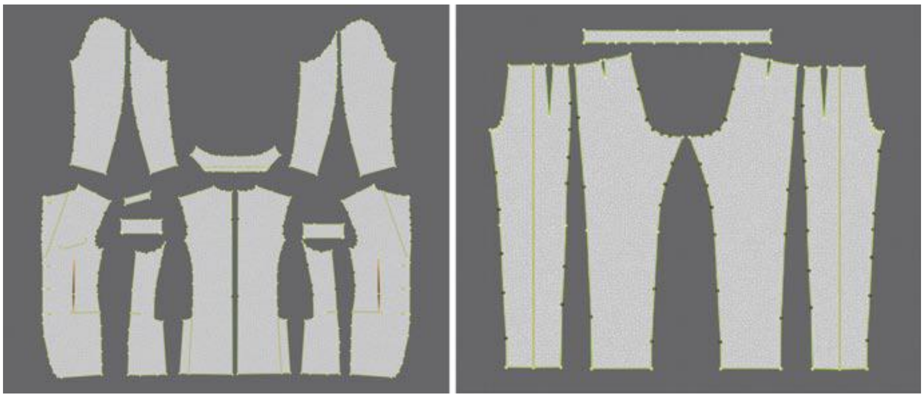

Figure 3.7: *Outer shell pattern of a men costume [30]*

Pattern Placement

The 2D patterns that represent the cloth surface are displayed on a grid in the simulation software. Later, around the virtual mannequin the planner patterns are placed. In order to bring the pattern to the closest position to the body surface, a manual placement is implemented with an automatic function. An approximate initial positioning is necessary as it is considered that the seams will gather the edges of each pattern together. To accelerate the process and in order to obtain a precise final garment (Figure 3.9), the space between two seam lines should be as small as possible [30].

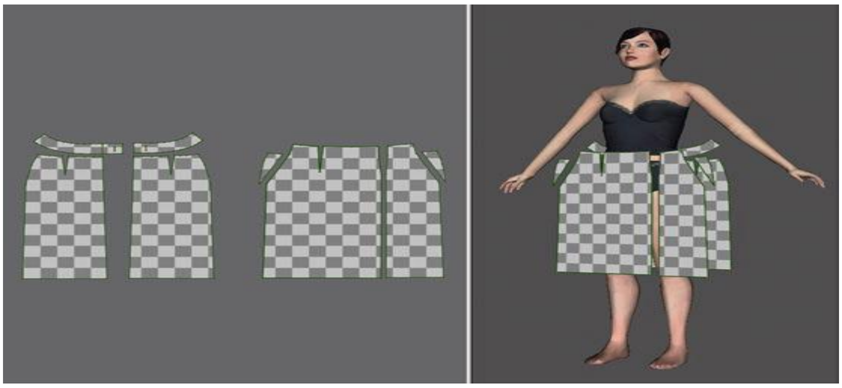

Figure 3.8: *2D pattern placements on virtual human [30]*

There might be some small initial problems that can be automatically solved through the collision detection. The pattern should not interpenetrate itself and the body initially. Furthermore, in the simulation software a fully automatic placement method is available, which works according to a placement file that has been created previously from a similar garment positioning. This automatic placement is however recommended for derail garments with similar pattern pieces [30].

Seaming

The seaming can be executed after the placement of the patterns around the mannequin. The seams are indicated with a different color line than the marker lines etc in the simulation application, e.g., in Figure 3.9 the seams are indicated with red lines. The seams are forcing the pattern to approach, and to pull the matching pattern together during the simulation process.

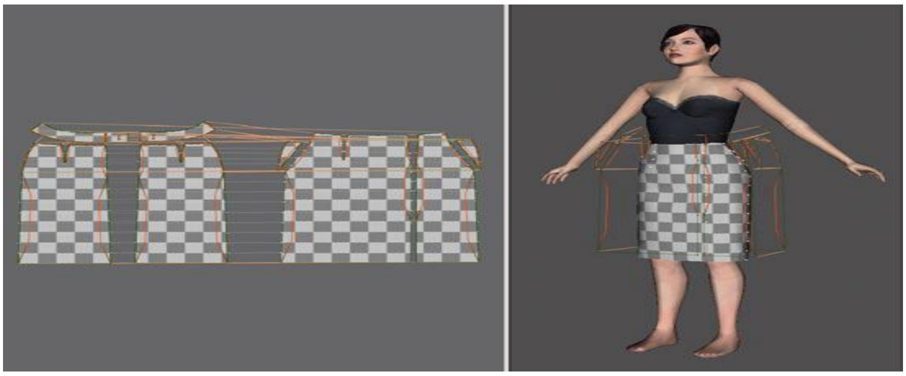

Figure 3.9: *Women skirt with seams indicated by red lines [30]*

There are several types of seams available, and they describe different ways of how the surfaces are connected (close mesh or open). Several seam parameters are available as well in order to imitate different seam characteristics [30].

Fabric Properties

Until recently, it has proven very difficult to predict fabric properties accurately and to view the effect of fabric on the body. Today, textile manufacturers test fabrics to gather their physical attributes, such as the bending of the fabric due to its own weight, the friction of the cloth against the body, and stretch in the x and y directions. Shading, transparency, and sheerness of fabrics, and the ability to import trims into the application also add to the realism of garment simulation [31].

According to N.Magnenat [32], the applied virtual fabric is composed in two components. First, a texture map containing the visual information of a textile is needed. This texture map should be a good quality picture of the fabric, and it should show the smallest repeat. Secondly, at this stage the mechanical and physical parameters have to be applied to the garment. The correct derivation from real fabric characteristics plays an important role as only precisely computed fabric characteristics can visualize different fabric qualities.

Garment Fitting

Once the garment properties and texturing is completed, the fitting of a garment can be executed by calling a mechanical simulation, which in other words is forcing the surfaces to approach along the seam lines. The surface is deforming according to the shape of the body. First, the simulation engine uses a simplified mechanical model that is optimized in speed by leaving the physical parameters and environment parameters behind the calculation. After this first simulation in which the garment has fast approached to the shape of the body, a second mechanical model is taken for the actual simulation. This simulation is executed until the fabric is dynamically stabilized in a static position (Figure 3.10).

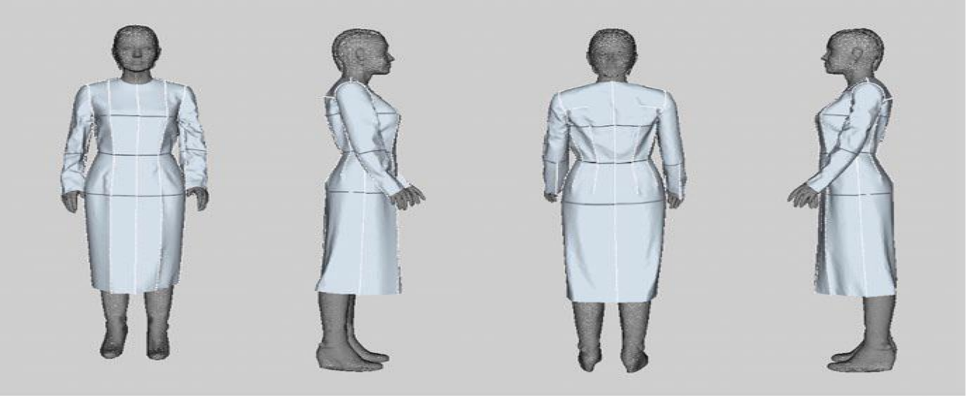

Figure 3.10: *Virtual static fitting [30]*

According to the movement of the virtual actor, the realistic clothing animation is simulated. This is possible because of the collision detection and friction with the surface of the body. The adjustments of simulation parameters can be different from those used during the process of seaming and assembling of the garment. The realism to the animation of clothing on the virtual mannequin is obtained by the mechanical simulation [30].

4 VIRTUAL TECHNOLOGIES

Wide research has been dedicated in the recent years to cloth modeling techniques, since cloth modeling has become a topic of large investigations in computer graphics as well as CAD/CAM systems and web shopping modules. Labored garments and drapes, in fact appear as key visualization elements in animation movies, cartoons, etc. Nowadays, a strong impulse comes from the clothing and fashion industries where there is an increasingly huge demand for the CAD tools to assist the whole design process [33].

4.1 Current Virtual Technologies

Until now different systems for virtual cloth modeling have been developed by scientific or commercial communities with different points of views and goals. Figure 4.1 presents a high level classification of some tools used in computer graphics and industrial design. Software systems for garment design focus on definition /construction of detailed garment shapes for real manufacturing according to different 2D/3D modeling tools [33].

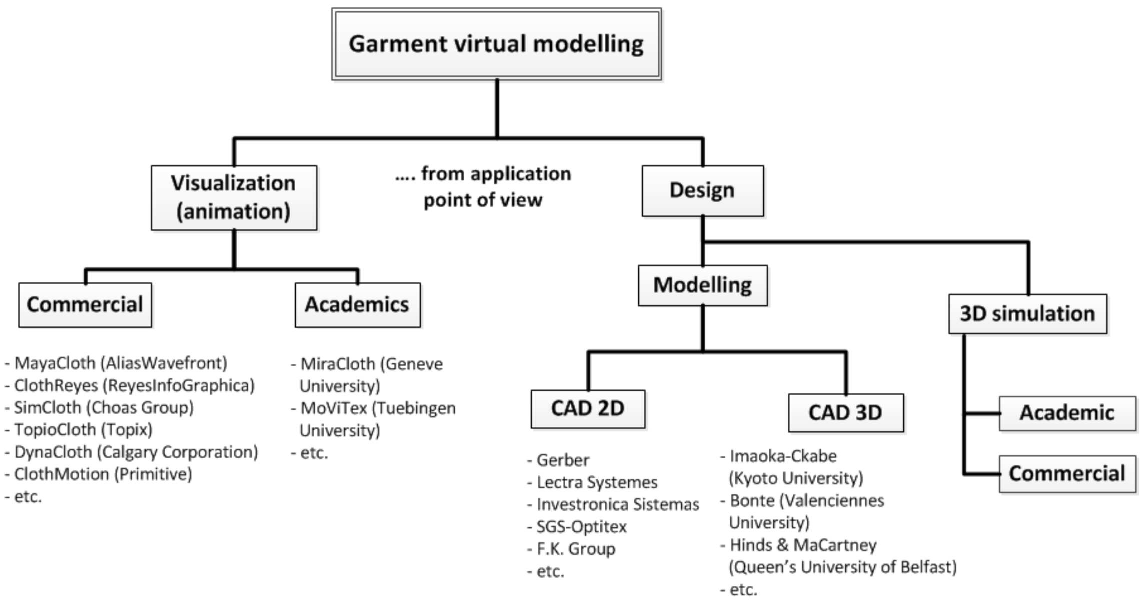

Figure 4.1: *Different systems for virtual cloth modeling [33]*

However most researchers have focused on the two dimensional pattern generation, and thus the quality of the pattern still depends more or less on the expertise of the pattern designer [34]. Although several 2D CAD systems are present in the market for pattern drafting, sizing, nesting, and marker making together with CAM modules for cutting and sewing. Therefore, there is a lack of effective garment oriented CAD packages to design directly in 3D and provide the medalist with tools for shape modeling and cloth behavior simulation [33]. Also according to Jin Wang at el [35], current 2D garment computer-aided design (CAD) systems focus more on 2D pattern designing, grading, typesetting and so on. It tests the garment design results by assembling 2D patterns and draping them onto a virtual human body to do some simulations. It is not intuitive enough and needs the designer to have accomplished skills and rich experience.

Many 2D CAD systems and automated cutting/sewing devices that are being used, they involve many human factors such as creativity of stylists and technical skills of dress-makers etc, thus making it difficult to have a complete automation in the whole apparel design process. Because of the involvement of human factors and not having a complete automotive design process in the 2D CAD, there are several levels of design complexities that have to be faced while defining shape, assembly rules and aesthetic/functional details of real tailored garments. A significant example of a particularly complex and labored garments (Figure 4.2) is a classical mans jacket. This garment originates from a large number of 2D panels corresponding to front, back and side parts, sleeves, collar, lapel, etc. with complex-shaped borders connected with each other by means of various darts and single/multiple seams. Sewing needs to be carefully applied with different degrees of tightness/looseness, depending on position, function and shape curvature effects (e.g., roller) by considering possible differences in the length and shape of borders that have to be joint together with definition of markers and constraint points.

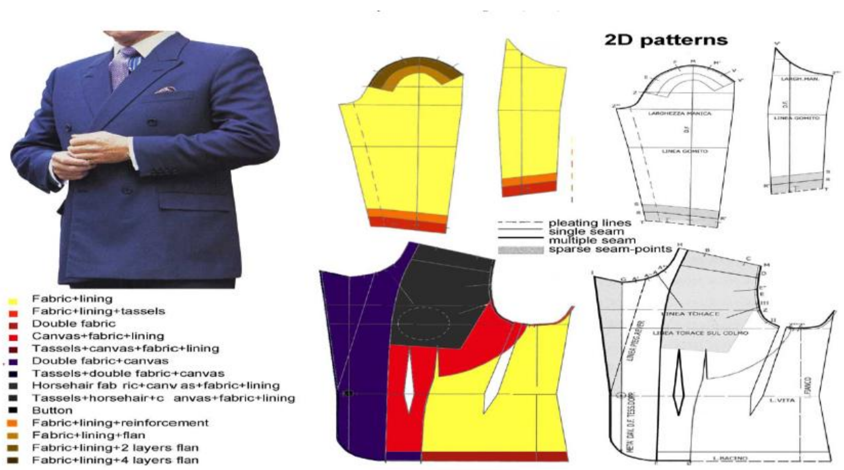

Figure 4.2: *A man's jacket: 3D-2D process with specifications of fabric layers, seams, darts and pleats [33]*

Alongside having many parts which have different shapes etc, the complexity of male jackets is also the result of a multi-layered fabric composition following well-defined rules with fabric layers varying in number among the several jacket's structural parts, and made of different heavier or lighter materials (cotton, canvas, linen, horsehair etc). Figure 4.2 shows the multi-layered structures of jacket's front part and sleeve as well as types of sewing lines. Stuffings for shoulders are placed to strategically correct shape proportions along horizontal directions, emphasizing larger shoulder-torso parts typical of male clothing. Small aesthetic and functional features enrich the structure of the jacket, e.g., buttons, hooks, external and internal pockets and other finishings. Last but not least, the different sculptured or smooth volume effect can be controlled / forced by starching, pleating, ironing, and other several mechanical / chemical actions inducing permanent or semi-permanent deformations on jacket's fabrics [33].

By using the 3D virtual technology, it is possible now to reconstruct such a complexity in a fully computerized way. The 3D garment design is more intuitive and easy to generate a fitted garment. There is a tendency of the garment CAD to turn from 2D to 3D with the development of 3D laser scan and computer graphics. Some studies have already focused on the 3D garment generation, modeling, pattern design and flattening, and have achieved the preliminary individual customization of 3D garment design [35].

4.2 3D Virtual Technology

Three decades ago, 3D technology use in the fashion industry was limited to a few adventurous manufacturers, and was largely dismissed by the apparel sector. Today, pressure in the apparel market to produce more collections under shorter lead times has led to a veritable 3D revolution affecting the industry as a whole. Cost reduction, enhanced creativity, and improved communication are only the beginning of what 3D technology has to offer this complex and dynamic market. 3D design technology by 1990 was still not introduced in fashion industry, but it was commonly used in aeronautics, furniture, and many other industries in that times. There were only few apparel companies who wanted to experience this technology. In addition, because of the complexity of the original 3D programs, fashion designers who found the technology too difficult resisted adopting it. Only in the last decade 3D technology has made its revolution and gained acceptance as both a design and a merchandising tool in the apparel industry. It is now recognized for its effectiveness in streamlining product development, and is applied throughout the supply chain [31].

A scheme of the 3D Process for garment designing is presented in Figure 4.3, with the goal to determine the mutual relationship of the production preparation processes and the structure of the informative and software means have been shown. A complete 3D designing process would exclude different working stages connected with constructing and constructive modeling, 3D imitation and creation of a virtual prototype [36].

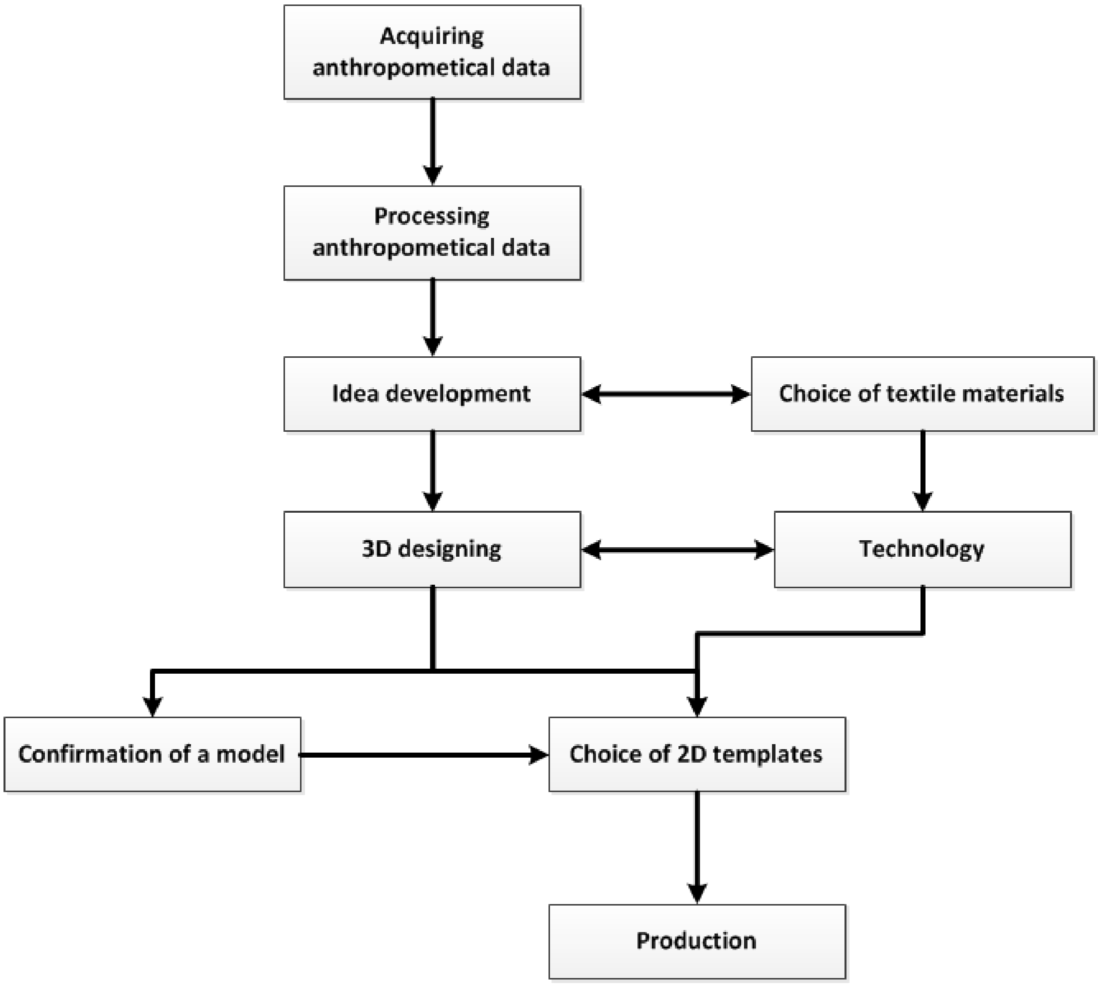

Figure 4.3: *A 3D process of garment designing [36]*

Commercially available 3D CAD systems based on their working procedure to create 3D designs can be roughly divided into the following three groups [37]:

- 3D Interactive System,
- 2D-to-3D Approach or Simulation System.
- 3D-to-2D Approach or Unwrapping System.

3D Interactive Systems allow the designer to develop garment silhouettes and styles in a 3D environment according to their preference. This interactive system includes software's such as Virtualfashion from Reyes Infografica (Spain) and Automatic Pattern Generation System (APGS) from TPC (HK) Limited (Hong Kong) etc [37].

In the 2D-to-3D simulation system, there can be different working approaches adopted; a 2D-sketch-based 3D simulation approach is one of the approaches where 2D patterns are sketched manually, and later assembled through a virtual sewing procedure to produce realistic draping simulation. This type of CAD system allows the designer to make a sketch of the garment onto a 2D view of a mannequin as shown in Figure 4.4, and it can generate 3D virtual garment from the 2D sketch [37][38].

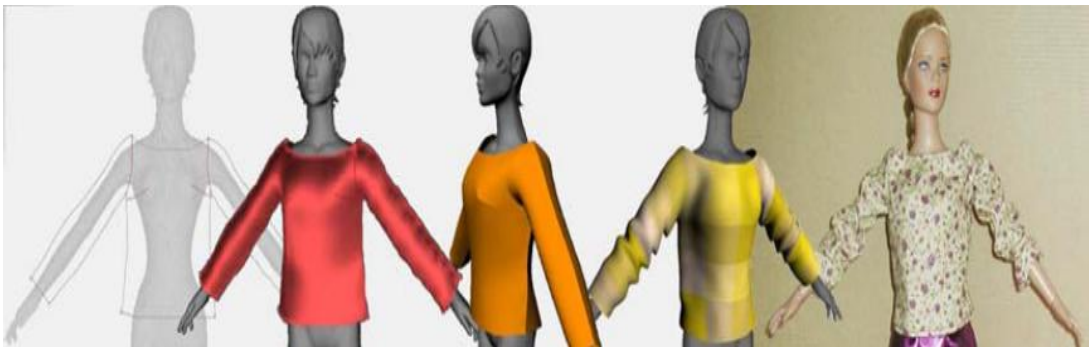

Figure 4.4: *From 2D sketch to 3D virtual garment [37]*

Importing 2D pattern pieces from an appropriate 2D CAD software to wrap them onto a virtual model to visualize the virtual product, and also to simulate fabric drape and fit is another version of the “2D to “3D”design approach that works in the environment of 3D CAD systems which capitalize on this approach. In this approach, the flat pattern pieces are placed on a virtual body and are joined together to produce virtual clothing as can be seen in Figure 4.5 [37].

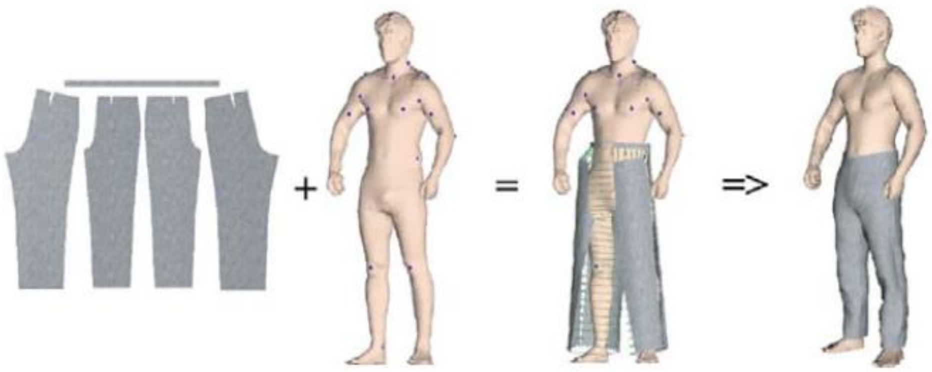

Figure 4.5: *2D to 3D design system [37]*

The 2D to 3D approach or simulation system to clothing design has successfully in a significant number of clothing CAD systems that are available in the market. Commercial software packages, such as Vstitcher from Browzwear (Israel) , Accumark Vstitcher from Gerber (USA), Modaris 3D Fit from Lectra (France), Optitex 3D Runway, Vidya from Assyst (Germany), Haute Couture 3D from PAD system Technologies Inc. (Canada) and efit Simulator from Tukatech (USA) belong to this approach of applications.

The 3D-to-2D approach provides a way for designers to create garments in a virtual 3D environment; nevertheless the resulted garments are usually of simple style, for example with single layer [38]. In 3D to 2D technology virtual body surface generation is required. 3D body scan data, B-spline curve and convex hull are mostly used for body formation. Quadrilateral mesh and triangular mesh are the types of uniform mesh which are used for body formation. In the image analyses sections, various flattening systems and virtual draping systems are the systems which have to be dealt with. Accuracy is described in the evaluation section. The algorithm of technical computer aided design (CAD) is shown in Figure 4.6 [39].

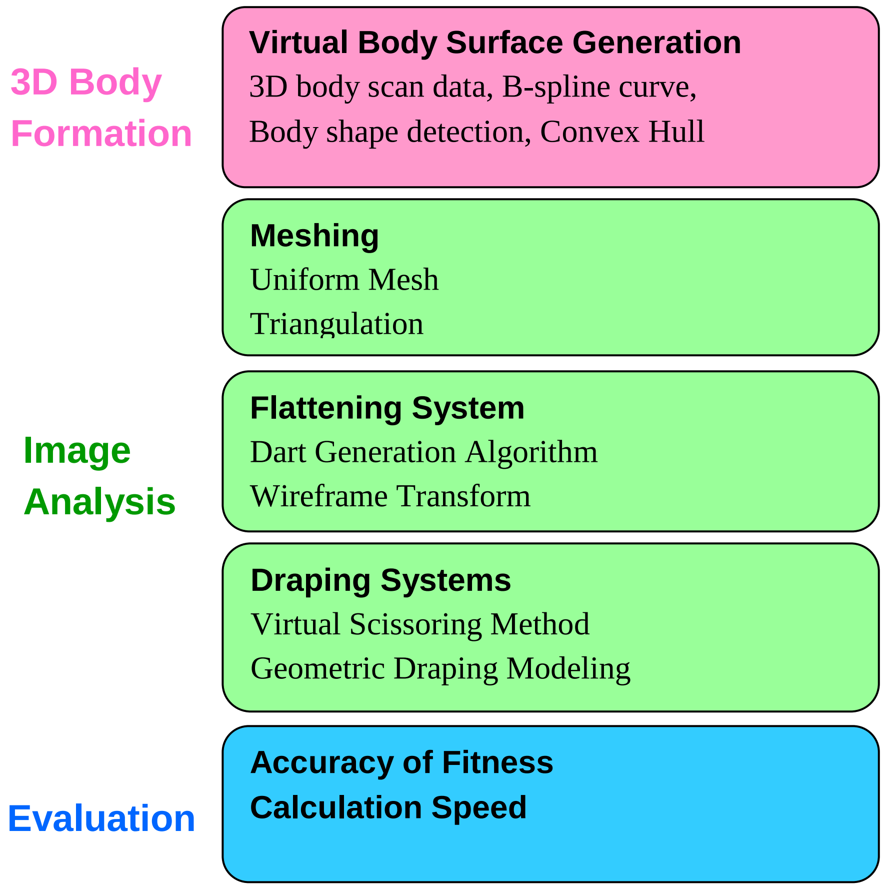

Figure 4.6: *Computer Aided Technical Design [39]*

3D-to-2D process typically starts with stylists' creative ideas, normally 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 patterns with corresponding fabric layers (3D-to-2D stage). 2D fabric panels are then assembled and sewn together to get a 3D garment shape as close as possible to the original stylists' idea (2D-to-3D stage). Procedurally, of course a more detailed sequence of design/manufacturing steps has to be considered, involving aspects such as:

- Definition of a reference 3D shape.
- 2D patterns definition/extraction (2D models).
- Definition of assembly rules (seams, darts, overlapped).

- Layers, buttons, etc.
- Definition of materials.
- Cut of 2D fabrics (single layers).
- Assembly of fabrics by layer overlapping.
- Assembly of one- or multi-layered fabrics along border.
- Parts (seams, darts, etc).
- Mechanical/chemical post-treatment of textiles by shape.
- Deformation (pleats, ironing, etc).
- 3D configuration/placement over supports or external.
- Objects (e.g., mannequins).
- Analysis of the final garment's shape and behavior in the 3D physical space.

These common aspects help in defining a computer assisted garment design methodology. The apparel that incorporates these mentioned aspects will be reaching accurate simulation of garments' shape and behavior for virtual prototyping tasks [33]. 3D to 2D unwrapping systems includes the software packages: 3D Interactive software from TPC (HK) Limited (Hong Kong) and the flattening tool of 3D Runway from OptiTex International (Israel). These two mentioned software packages provide the capability to execute pattern unwrapping in a very limited context, but only for close-fitting garments. The software DesignConcept 3D from Lectra is also capable of executing 3D to 2D pattern unwrapping to some extent, but mostly it is being used in the car seat designing and technical textile industry [37].

4.3 Impacts of 3D Technology alongside Concept -To-Shelf

For any fashion company, one of the major challenges is ensuring that the fit of a garment is as close as possible to its target customer. In most cases, this implies providing a sample, which means patterns need to be made, fabric cut, pieces sewn together, and products then transported to the client for a fit session by sea or air etc. Some retailers and brands still fly human fit models to Asia or other contractor locations for on-site fit sessions. This is an expensive and lengthy process, which may require several iterations before the garment is fit-approved or eventually rejected from the line. 3D technology at the design stage can help reduce cost and time-to-market, contributing to a more efficient and profitable process by reducing the number of samples required and their associated costs [31].

4.3.1 Impact of cost effectiveness in prototyping

How many new styles are introduced by a company is an important cost factor in development and manufacturing. Some fashion companies have an adoption rate as low as 25%. A single prototype can cost anywhere from $250 to $1,000 and much more when design and development costs are factored in [31]. It will add up very significant savings, if the need for thousands of physical prototypes per year and the related shipping charges are eliminated. Since companies can now decide whether or not to take a product to market using 3D technology without a physical prototype, or fewer prototypes, the cost of rejecting a style (in terms of material, labor, and time) is significantly lowered. According to Jan Rosenberg [40], the usage of virtual technology can cut the prototype need and lead time from 10% - 60%.

4.3.2 Impact on the fabric drape and pattern modeling

The information which can be achieved by using 3D virtual technology enables to see the pressure points or stress points where the fabric might be too tight against the body, which allows a much more realistic drape during the rendering of the finished garment. The subtle differences in various fabrics are immediately apparent and designers can even test new textiles still under development. This facilitates and accelerates the decision-making process, even before a garment sample is manufactured or a strike-off or handloom produced.

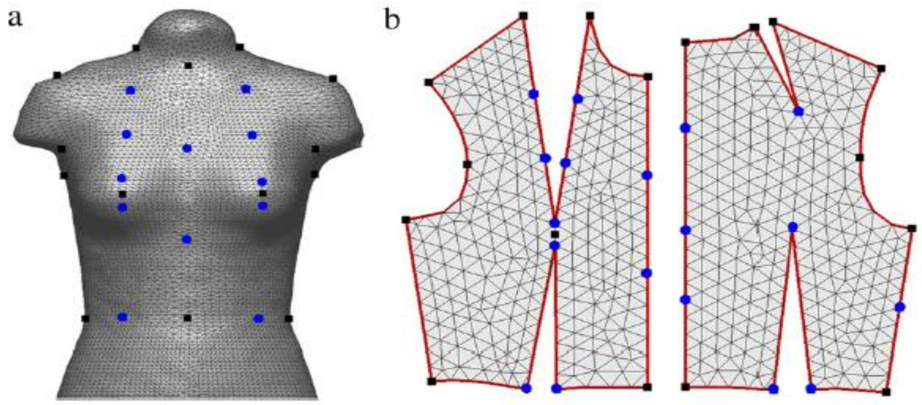

Figure 4.7: *(a) Feature points on human model with predefined body features (black square points) and system generated auxiliary points (blue circle points) and (b) corresponding feature points on the front and back pattern pieces [41]*

Most of the advanced 3D applications available nowadays combine patterns with particular fabric properties and stitching lines to simulate how the fabric will fall or drape. 3D body scanning machines take all the millions of points of a company's fit model to create an avatar of the same body, which can then be used to accurately predict the ease and tightness of a garment. Later, the user can adjust the pattern pieces in the 2D pattern-making application and view them in the 3D application to re-simulate and once again check the fit. These rough modifications are easily transferred to paper patterns for fine-tuning. In the past, work done on paper patterns required a multitude of tedious manual adjustments. One of the very time consuming tasks was fit-checking that would have taken hours, or even days [31].

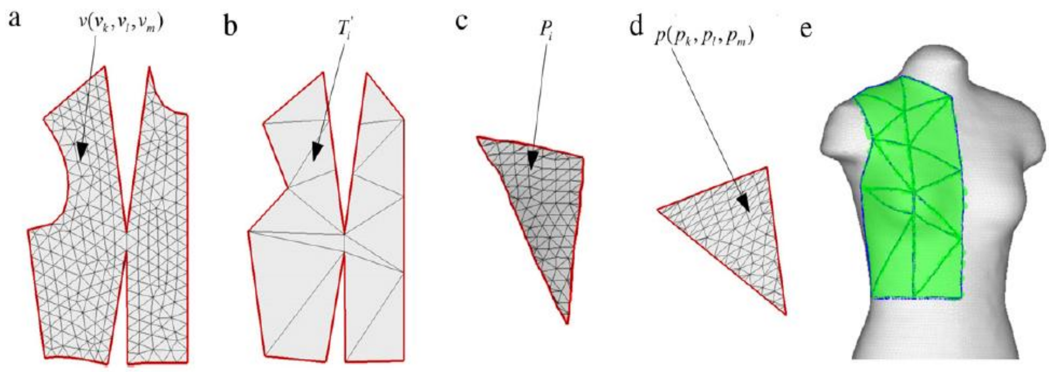

Figure 4.8: *(a) Original garment pattern M; (b) ancillary pattern generated by constrained delaunay triangulation M'; (c) a 3D patch segmented from human model Pi; (d) flattened 2D patch by Harmonic map; (e) shortest path graph on human model and the final 3D configuration [41]*

Today's 3D applications include automatic functions specifically designed to reduce repetitive tasks and allow trained technical designers to adjust patterns in a matter of minutes. Designers in all markets, whether childrenwear, menswear, womenswear, sportswear, or any other kind of apparel, are under the same pressure to produce high-quality products in a limited amount of time. 3D technology offers a realistic, easily accessible solution to the historically arduous task of full size range fit checking [31].

Figure 4.9: *(a) Mapping results of 2D pattern around human model. Using the pattern M*, the seam position of two seam line can be mapped to the same coordinate (the red lines specify the mesh boundary); (b) mesh after seam operation; (c) mapping the front and back pattern pieces around human model to form a complete garment. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) [41]*

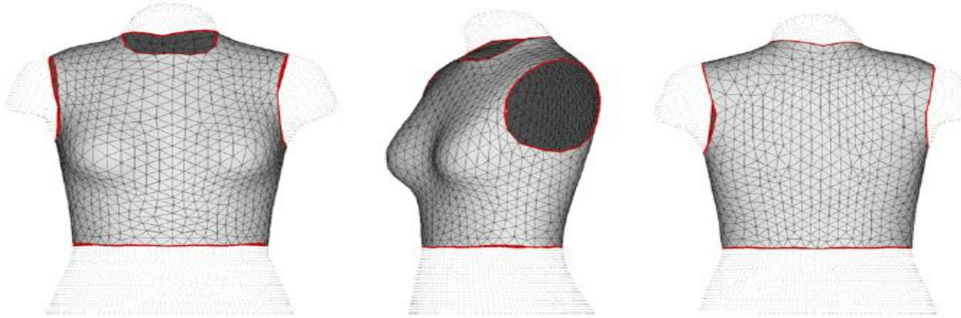

Figure 4.10: *Complete garment after sew operation (front, side, back views) [41]*

4.3.3 Impact on overall product development time

3D virtual technology is bridging the gap between design and development by improving communication between internal and external merchandising, design, technical design, sourcing, vendors, and customers that significantly reduce overall product development time [31]. Now many designers are comfortable enough with 3D apparel technology to make quick design decisions on how a garment looks in different colors with different sizes of motifs and logos and in different fabrics. In turn, the ability to produce close to the market instead of having to plan far in advance allows companies to avoid getting locked into poor designs or create ill-fitting garments. In the same way, today's 3D applications can be used to create virtual lines or ranges of garments for review and discussion over the Internet by design teams across the globe. This technology allows the designer to communicate changes quickly to the pattern maker and see the results within hours instead of days or weeks. According to Jan Rosenberg [40], it anticipates market research by 20% - 90% as well.

Figure 4.11: *Virtual shirt range created for designer communication [42]*

Speed-to-market is a key in the quest for an ever-shorter product development cycle. Because with a lengthy product development process, it is difficult for companies to catch up with the fast-selling items with updated variants and complementary items. This 3D technology enables companies to tweak their designs and approve them digitally with minimum sample making. This is how the designs get into the stores much faster than in the past, enabling companies to capture continuing sales.

4.3.4 Impact on carbon footprints of the company

As discussed by Jan Rosenberg [40], if the companies are checking the complete size range of a garment virtually, fewer prototypes have to be cut and sewn. Reducing the millions of prototypes companies manufacture to check fit, color, and the overall look of a garment reduces the energy used for shipping and transport as well as the amount of chemicals used for preparing, washing, dying, and treating fabric, and results in less waste from each operation in that process. Therefore, 3D fit technology combined with computer-aided design (CAD) pattern-making may also significantly reduce a company's carbon footprint from 10% - 30%.

5 AVAILABLE VIRTUAL TOOLS

As mentioned in Section 4.2, based on the working procedure to create 3D designs, normally commercially available 3D CAD systems can be divided into three groups: 3D interactive systems, 2D-TO-3D simulation systems and 3D-TO-2D simulation systems. But in this research, a different approach is adopted by dividing the commercially available 3D CAD Systems according to their applications. Dividing the virtual softwares in such a way will enable the use of one software for different categories i.e., DC3D by Lectra is used for application in tight fitted garments, application car seat covers development and also it can be used in technical textile applications. The categories of 3D virtual systems upon their application are presented as follows:

- Application outerwear/protective garments.
- Application tight fitted garments.
- Application car seat covers development.
- Application textile reinforced lightweight structures.
- Application textile packaging.

As this research only focuses on fashion apparel industry so the 3D virtual tools available for application outerwear/protective garments and application tight fitted garments are discussed in detail other categories of virtual tools are discussed briefly in the following sections.

5.1 Application Outerwear / Protective Garments

This category of 3D virtual tools is mostly used for lose fitted garments designing that can be outerwear e.g., trousers, dresses etc or protective clothing e.g., fire fighting jackets etc. For constructing loose fitted or outwear garments, it is necessary to develop 3D construction method for a virtual "second skin", which covers the body contour with the offset or eases in order to ensure the desired comfort and fulfill fashionable demands [43]. 3D pattern development for loses fitted garments step by step is shown in the flow chart presented in Figure 5.1, and a process chain for loose fitted garment (men trouser) is shown in Figure 5.2.

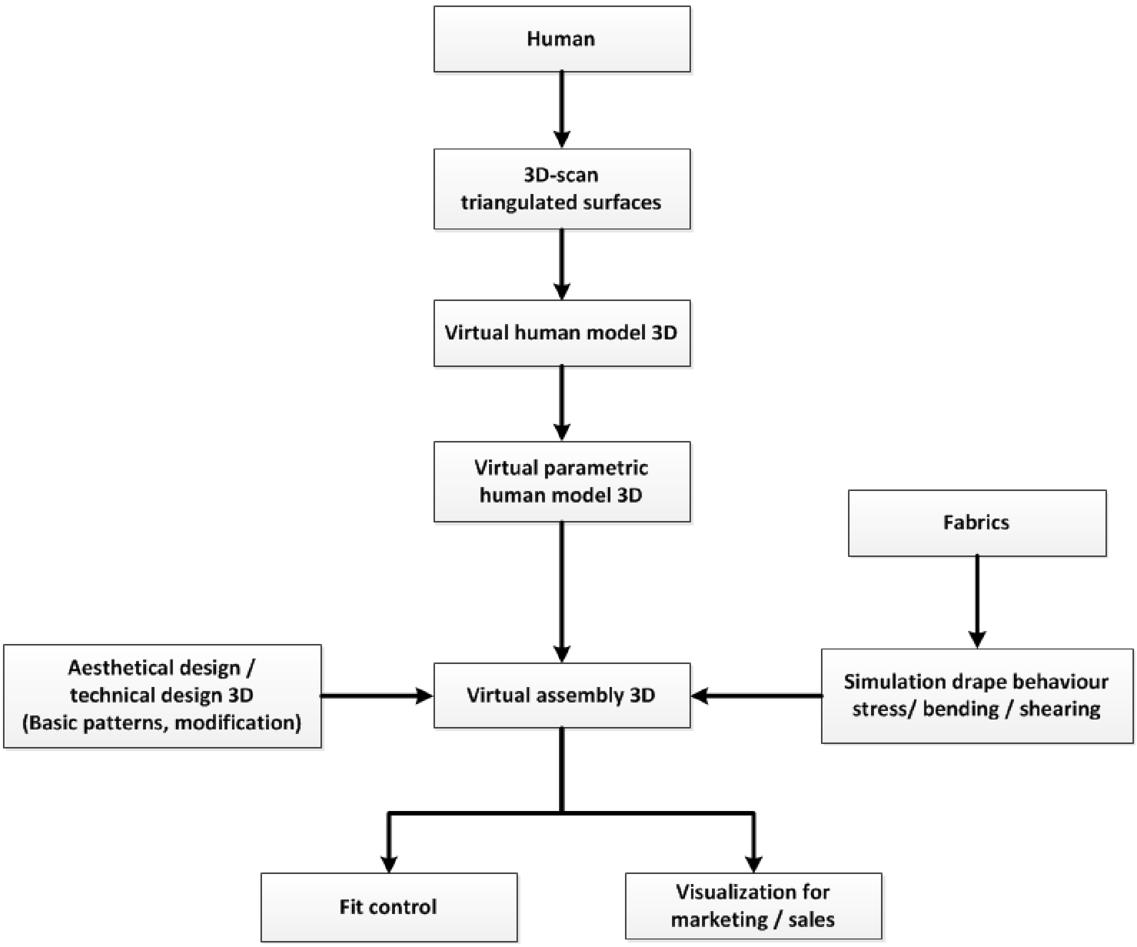

Figure 5.1: *Flow chart for 3D pattern development for loses fitted garments [28]*

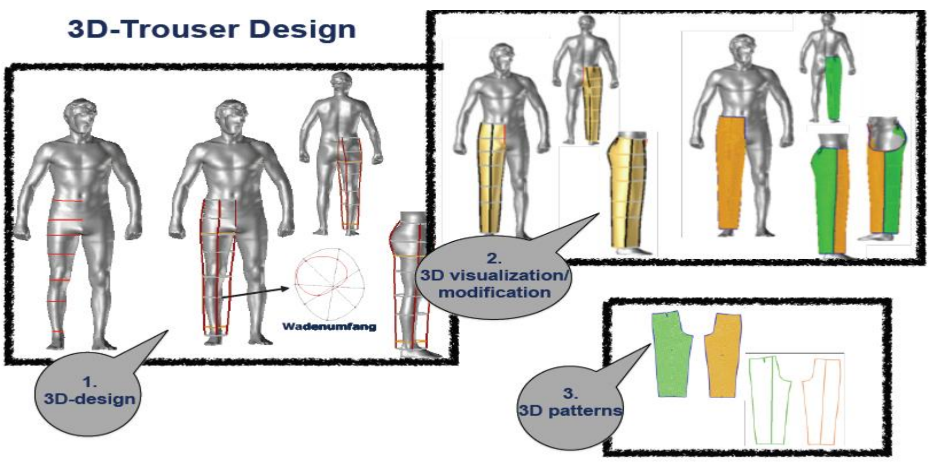

Figure 5.2: *Process chain for loose fitted garment (men trouser) [28]*

The major potential outerwear producers which use relevant 3D virtual tools are Hugo Boss, F.W. Brinkmann GmbH, Rosner GmbH & Co, Oliver, Esprit etc. Major protective clothing producers are Boco GmbH & Co, Eurodress GmbH & Co and ICICLE etc. The main 3D virtual tools available for this category are explained as follows:

5.1.1 Modaris 3D Fit by LECTRA

Lectra is the world leader in integrated technology solutions that automate, streamline and accelerate product design, development and manufacturing processes for the soft goods industries. Lectra provides CAD/CAM equipment, and associated services which are specifically designed for industries using fabrics, leather, technical textiles, and composite materials to manufacture their products. It serves major world markets: fashion, automotive, furniture as well as a broad array of other industries (aeronautics, marine, wind power, etc) [44][45].

Modaris 3D Fit software provided by Lectra combines the accuracy of CAD with virtual product visualization, providing the best visual simulation capabilities available for virtual prototyping. Modaris 3D Fit allows pattern designers to simulate in 3D, a pattern design developed in 2D. Modaris 3D Fit is unmatched in its ability to control garment fit, validate styles designs and specifications, and accelerate approvals for entire collections [46]. It constitutes a major CAD breakthrough and enables simulations and validations of styles, fabrics, motifs and color ranges. It allows pattern designers to check garment fit in various fabrics and sizes. It provides virtual review of prototypes between brand and subcontractors, and presentation and validation of collections elements [47].

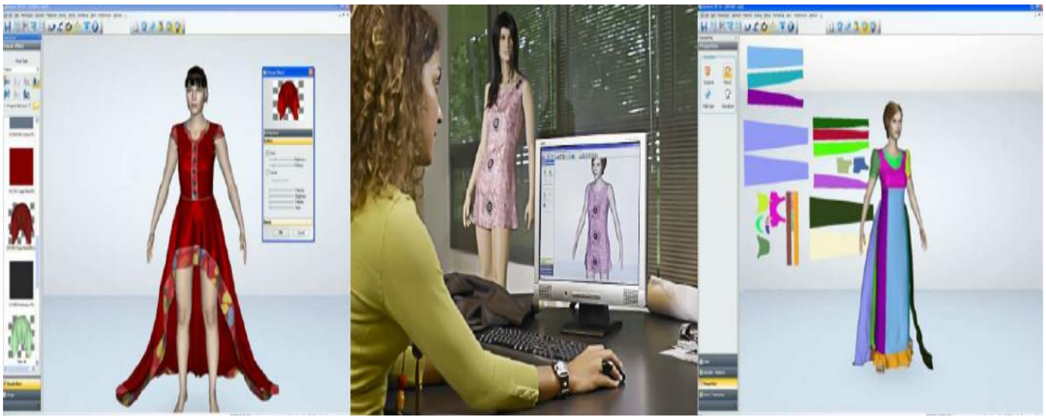

Figure 5.3: *Modaris 3D Fit by LECTRA [47]*

Modaris 3D fit is now made more advanced by adding two new parametric mannequins to its previous eight. These new mannequins a “plus size” male for simulating garments sized 58 to 66, and a female for sizes 44 to 52 have been designed correspond to the new market segments. Also In addition, Lectra has reinforced Modaris 3D Fit’s capacities for checking look and fit by adding new postures for all its parametric mannequins. Modaris 3D Fit also features an enriched library of materials the most complete such library on the market, now with twenty new supplementary materials bringing the total number to 140. This makes now 3D simulation possible for certain knits as well as technical and/or professional clothing [45][46][47]. A comparison of the specifications of available Modaris modes can be seen in Table 5.1 on the next page.

Table 5.1: *Comparison of the specifications of available Modaris modes [47]*

Model	Specifications
Modaris Mode	This is an ideal solution for integrating automated design into working methods. Modaris Mode facilitates the importation of pattern files and the digitalization of paper patterns. It also enables users to perform basic modifications, high quality grading in all sizes, industrialization tasks, and pre-production preparations.
Modaris ModePro	It is a solution built around all the applications and tasks involved in the pattern development process. Modaris ModePro integrates on-screen management of pattern design and modification. In addition to Modaris Mode it facilitates advance verification of pattern pieces. It has the capability for information exchange with the currently available CAD systems in the market.
Modaris ExpertPro	ExpertPro model enables further gains in terms of innovation, product quality, and pattern design. This solution offers companies the means to create more models and increase development office productivity by up to 50%. It enables users to organize pattern and product ranges and also keep a record of the designs and pattern pieces created. Thus allows 80-90 % reuse of the elements designed for one collection as the basis for a new one.
Modaris 3D Fit	It is a virtual prototyping solution, which extends Leuctra's Modaris offer to cover the entire pattern development process. Modaris 3D Fit facilitates fast and reliable prototype checks earlier in the product development process, reducing prototype costs and time by up to 50%.

Features of Modaris 3D Fit

- Efficient workflow: Two-dimensional patterns originating from Lectra's benchmark pattern-design solutions, Modaris are assembled and translated into three dimensions on a virtual mannequin in the desired fabric.
- Virtual mannequins: Mannequins created in dedicated 3D software or scanned physical mannequins can be imported into Lectra Modaris 3D Fit. Parametric mannequins simplify fit control for basic and graded sizes and customized mannequins enable to match brand targets.
- Garment style validation tools: To easily simulate various combinations of garment elements onscreen, a collection of easy-to-use tools for designers and pattern designers are made available in the new Modaris 3D Fit.

- Fabric library: Modaris 3D Fit has a library of 120 fabrics and their mechanical characteristics. The fabric sample library can be customized by Lectra and new or more specific fabrics can be added to the library to maximize three-dimensional modeling accuracy.
- Unmatched fit control: This application simplifies checking garment ease, balance, sewing lines, proportions, fabric drape, and impact on graded sizes.
- Collection content validation: By visualizing garments in various fabrics, motifs, and color ways product specifications can be reviewed. For ensuring that the physical samples created are as close to final product as much as possible, for this the collection content can be validated before actual samples are made. There is no waiting on physical samples to make decisions and creativity can be reinforced with optimal product combinations [46][47].

Benefits of Modaris 3D Fit

- Significantly reduces in number of physical samples required and in pattern design development time.
- Decisions can be made rapidly, accelerating product time to market.
- Shortens lead times for new products.
- Significantly reduces costs associated with creating and shipping multiple samples per style.
- Improves collaboration with virtual models that include all required data.
- Improves communication between all participants in product lifecycle, regardless of location.
- Improves communication and enhances cooperation between brands, outsourcing partners and subcontractors.
- Improves product quality.
- Reduces development costs.
- Manage product engineering in a collaborative and transnational environment.
- Capitalize on pattern-making resources and best practices [46][47].

5.1.2 Vidya by Assyst

The Human Solutions GmbH has taken over all software products, software related services and software related hardware supplies of the former Assyst GmbH from that company’s insolvency estate. At present, there is a cooperation developed between Assyst, Human Solutions and also AVM Solutions. This cooperation has grown into a successful virtual fitting and prototyping system allowing more than just integrated individual scanned mannequins and fitting the chosen apparel model on it [36][42][48].

Alongside iSize and Cad.Assyst, Vidya is one of the 3D draping software which can be used in the clothing industry for product-development and virtual fashion shows, and the games and film industry as well for making animated characters and other functions related to virtualization [48]. According to Thomas Baur [42], Vidya is real-time simulation of garments, simulation of material properties and virtual fitting of 2D garment patterns on a 3D body model. It offers complete integration with body scanning technology to develop customized virtual mannequins. Vidya also offers a set of readymade but customizable mannequins which are flexible in respect of size and shape changes to the designer's choice [37][48]. It works on the basis of 2D to 3D design principle as shown in Figure 5.4.

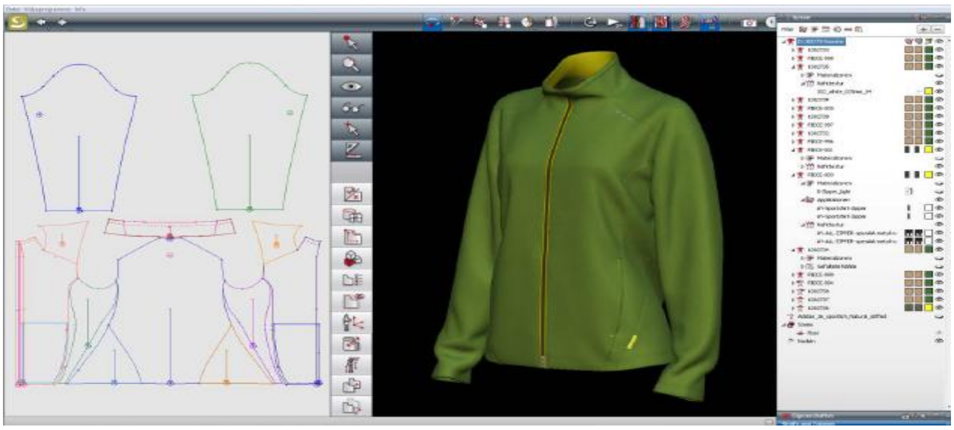

Figure 5.4: *2D Go's 3D Version 20.14 of Vidya [42]*

In order to produce a virtual garment, flat pattern pieces in a 2D CAD system can easily be linked with Vidya to three dimensional positions them on a selected mannequin. On the virtual garment material realistic simulation of drape behavior can be imparted by integrated drape engine. It can add seams, buttons, appliqués, seam lines, linings and folds as planed or imagined by the designer in order to make the 3D design even more realistic.

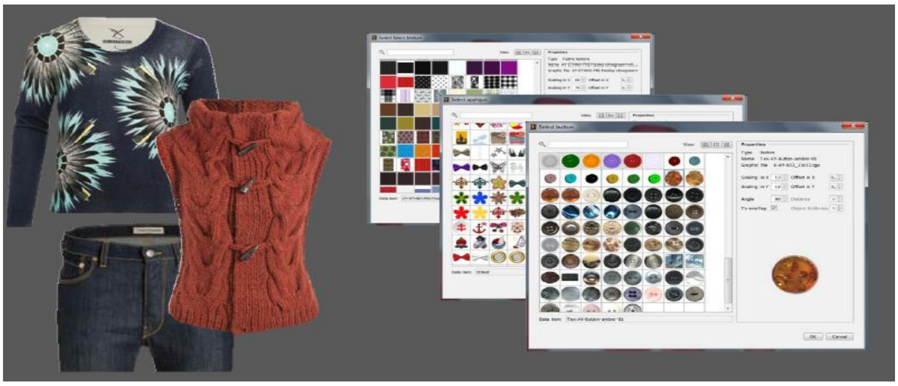

Figure 5.5: *Adding seams, buttons, appliqués, seam lines, linings & folds in Vidya [42]*

By using the texture mapping tools fabric checks, stripe, print and color can be reproduced. There is a wide range of available data base for the designer's selection during the garment simulization and visualization process i.e., generation and transfer of the pdf file with pattern placement including textures to the fabric printer. It is very effective communication tool within and outside the organization, and also Vidya delivers perfect models for further use in 3rd party tools such as DeltaGen, Maya, i.e., 3D StudioMax, DAZ, and Bryce etc [36][37][42][48].

5.1.3 V-Stitcher by Browzwear

VStitcher™ is 3D garment visualization and drape simulation software from Browzwear (Israel). Browzwear™ was established in 1998 in Israel, but now has been headquartered in Singapore with a global commercial presence both directly & through re-sellers (Gerber, Seamaco, grafis etc). According to Sharon Lim, managing director [49], Browzwear was the first to provide commercial 2D to 3D true-to-life (T2L) simulation for the industry and made 2D to 3D to 2D possible. 3D created by VStitcher™ is used for design, technical development, print media to sales and marketing.

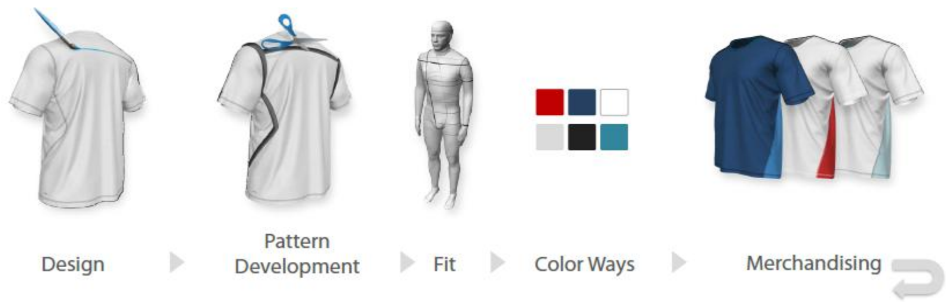

Figure 5.6: *Digital work flow provided by VStitcher™ [49]*

Now Gerber (USA) has merged this software with its pattern design, grading and marker making software AccuMark, and now it offers to market in the name off AccuMark VStitcher™ [37]. VStitcher™ has the capability of producing virtual prototypes from 2D pattern pieces and then assembling them directly on a virtual mannequin. This makes possible to use virtual samples for internal design reviews even well before the factory creates actual samples, as shown in Figure 5.7.

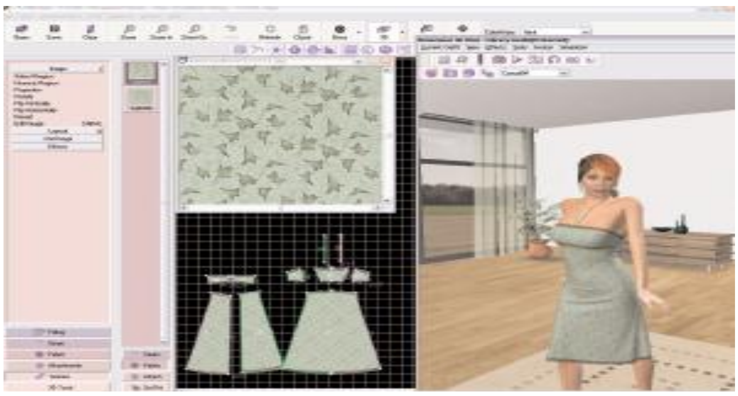

Figure 5.7: *Creation of virtual 3D sample from 2D patterns VStitcher™ [50]*

When needed or where appropriate, this software can be customized by means of a range of parameters such as body measurement, posture, skin tone, hair style and also the stages of pregnancy, since it comes with a set of built-in and integrated mannequins. Based on the physical characteristics, the fabric behavior can be realistically reproduced by using the drape module of the software [36][37][49][51].

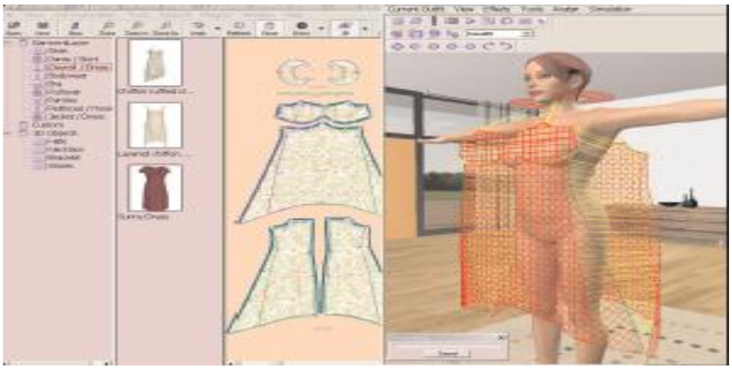

Figure 5.8: *View of simulated garments to evaluate fit by AccuMark VStitcher™ [50]*

3D simulation of the pattern pieces which needs to be modified automatically adopts the particular change as demanded by the designer as the software includes features of a 2D/3D reactive design. Therefore, there is no need for any physical prototype for fitting trial and finalizing the production pattern [37].

5.1.4 PDS Version 10/ Runway by Optitex

Optitex is a leading provider of 3D Virtual Prototyping & 2D CAD/CAM software solutions for the apparel, automotive, aeronautics, industrial fabrics and upholstery industries. 3D virtual tools provided by Optitex enable the user to lower costs, quicken time to market, and become more competitive. Optitex offers a number of products that can be used during the various stages of pattern making, grading, marking, etc [52]. Optitex's powerful Pattern Design System (PDS), which has many versions, makes very easy to create new styles, or use existing patterns to design patterns. PDS provides a full suite of features and functions that are designed with sewing product manufacturers in mind [52].

3D Runway is a garment simulation software package which can support both 2D-to-3D simulation and 3D-to-2D simulation unwrapping. It offers 3D Runway Suite of tools, which include tools such as 3D Runway Designer, 3D Runway Creator and 3D Flattening. First two tools support garment visualization and 3D draping based on 2D flat patterns. The 3D flattening tool of the 3D Runway is only used for tight fitted garment, which is mentioned in Section 5.2.4. The use of Optitex 3D Runway suite of tools makes virtual to become real. This suite of tools one by one is shown in Figure 5.9 - Figure 5.13 and explained briefly.

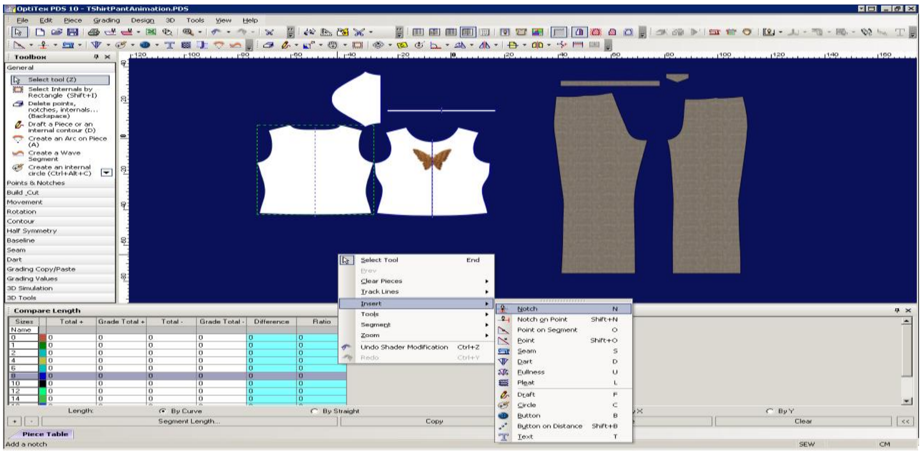

Figure 5.9: *3D Runway Suite of Tools [52]*

- 3D Creator for PDS: Directly in PDS, patterns can be easily draped on one of the several models included in the software or on users own model [53]. 3D Creator for PDS tool is shown in the following Figure 5.10:

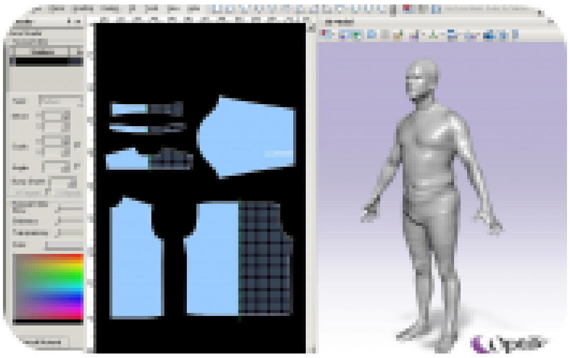

Figure 5.10: *3D Creator for PDS [52]*

- 3D Digitizer: This new technology allows the user to digitize in 3D view and see the results on the 2D pieces [52][53].

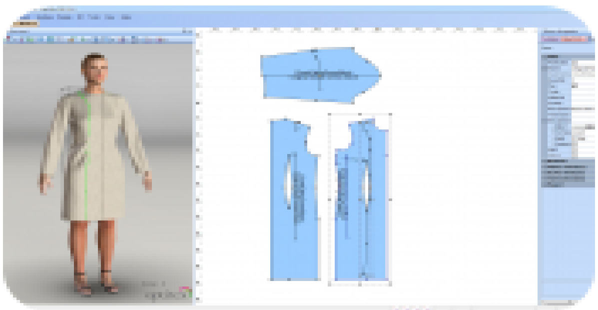

Figure 5.11: *3D Digitizer [52]*

- 3D Creator for Modulate: Offers a wide range of highly detailed parametric avatars, including more than 80 adjustable features [52].

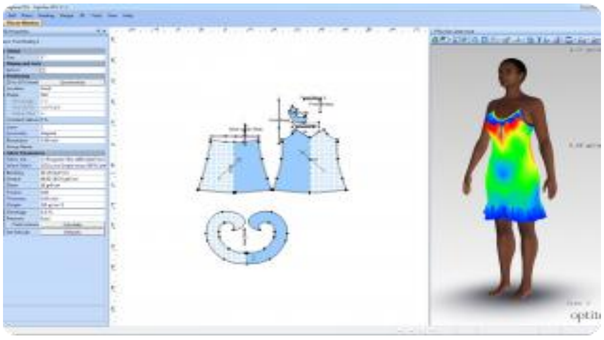

Figure 5.12: *3D Creator for Modulate [52]*

- 3D Designer: A tool used for communication between the retailer, subcontractor, designer, pattern maker, manufacturer and the engineering, merchandising and management departments. It allows for the visualization of pattern modifications instantly, in full 3D form, based on accurate CAD patterns and real fabric characteristics. It simulates all pre-production activities related to fitting, visualization, texture, and color variation [53]. 3D Designer tool is shown in the following Figure 5.13:

Figure 5.13: *3D Designer [52]*

OptiTex version 10 presents a significant advance to a more user-friendly pattern design / grading and 3D system, which the user finds far easier to operate. OptiTex version 10 incorporates:

- New File Structure to reduce memory usage and assure forward compatibility and XML connectivity.
- New license management architecture.
- A greatly improved user interface.
- New utilities to speed up the production process and connection between different departments.
- Additional tools and features to speed up actions and meet pattern design needs.
- New converters to eliminate data transfer difficulties and increase the flexibility of communicating with various CAD systems.
- A new online help site, including software documentation, knowledge base and tutorials are provided [52].

5.1.5 TUKA3D by Tukatech(USA)

TUKA3D previously known as eFit Simulator™ is another “2D-to-3D” simulation software suite that accepts 2D pattern pieces drafted separately to produce digital garment prototypes. Taking fabric properties into account, it exploits advanced cloth simulation technology to reproduce realistic drape and fabric nature. TUKA3D also comes with a set of virtual fit models just like other packages available of this software’s type. It can generate animation and a virtual catwalk of dressed models to facilitate evaluation of fit and style. In addition, it is equipped with a physical tension-mapping tool for the purpose of evaluating the looseness and tightness of virtual clothing on the mannequin. It supports online virtual fit sessions across the globe among the partners using the same systems and facilities to make dynamic storyboards for presentations purposes. The companies which are using this software provided by Tukatech include, Maggy London, Tesco, Phillip Van Heusen and Jones New York Intimates etc [54].

5.1.6 3D CAD System Staprim (Russia)

The 3D CAD system Staprim from Russia is designed for the loose fitted garments mostly i.e., coat, jacket, dresses and uniforms etc for mass production as well as individual product design. The patterns of cloths are created automatically by laying out the surface of the constructed model from three photos on a plane. This allows to solve a number of essentially important engineering problems e.g., to set high quality of layout of a product on a human body, to carry out maximum computerization of processes of cloths designing from the idea up to the layout of patterns, to estimate the created (virtual) model of a product before the manufacturing stage by rendering the image on a screen, etc [36][55][56][57]. A garment designed by 3D CAD System Staprim can be seen in Figure 5.14 below.

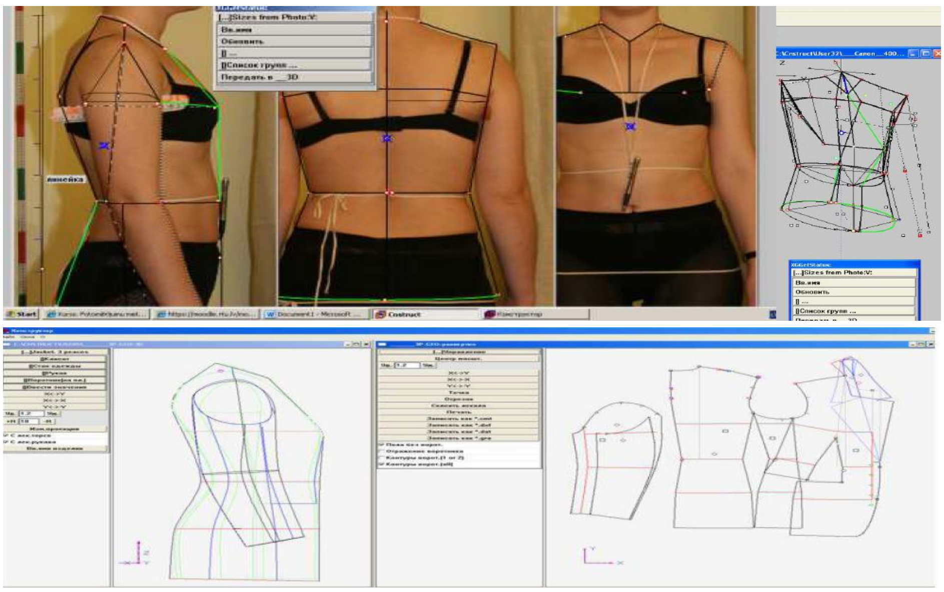

Figure 5.14: *Garments designing by 3D CAD STAPRIM [36]*

The process from the idea to the layout is computerized by merging the 3D CAD system Staprim with traditional 2D CAD Comtense provided by Comtense (Russia). This Comtense ensures the development of production pattern comprises: pattern creation, modeling, grading, marker making, plotting and CNS-cutter control file generation. This system is very suitable for creating different uniforms, since it has a unique option of creating well set construction for different individual figures, but only at the basic level not for special feature designing. The Melon fashion company from Russia is using Staprim since 1996 for creating new collection according to the demand [36][55][56].

5.1.7 Bernina My Label (Switzerland)

Bernina My Label is pattern-making software with integrated 20 different styles based on parametrical mannequin which can be changed for individual measurements. It is possible to make slight design details i.e., skirt longer, collar wider etc, and possible to change the wearing ease according to the requirement of an individual. According to Bernina [56][57], it is required to enter 47 measurements for any individual, according to these measurements a 3D model is generated using Optitex imaging software. After individual mannequin is created and saved, garment may be selected and simulated on the model. A perfect color can be selected from a virtual drawer full of fabrics [36][56].

(a)

(b)

Figure 5.15: *Bernina My Label (a) Generation of virtual model (b) Online sewing instructions [56]*

The garment can be virtually embellished with stitches, embroidery and buttons and also it is possible to vary the style properties as shown in Figure 5.16 below.

(a)

(b)

Figure 5.16: *Bernina My Label model (a) Virtually embellished with stitches, embroidery and buttons (b) Varying style properties [56]*

The model can be dressed and undressed as many times until the desired reflection is not achieved. The own label can be saved, emailed and printed. 3D animations make it possible to view the designed patterns with both the selected fabrics and embellishments [56].

5.1.8 ASSOL (Russia)

Assol 3D clothing design system which is in cooperation with AutoDesk, have created a garment designing module named ASSOL 3D Parametric on the basis of AutoCAD. This module provides the parametric designing of garment templates as well as parametric gradation of templates, using of different parametric and digitized mannequins for 3D designing of limited assortments. The AutoCAD being used as a base allows for more elastic connection of software and hardware [8][36].

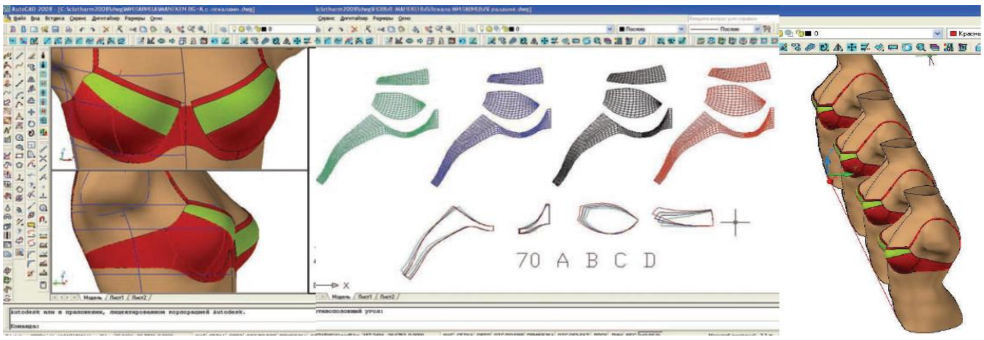

Figure 5.17: *Cloth designing in 3D space with ASSOL 3D parametric software [8]*

Assol 3D Parametric allows building the cloths in 3D space with completely controlling the appearance of the virtual product, degree of the fit and shape of the model line. Templates are created using the predictive algorithm deployment of three-dimensional surface details of clothes on the plane. The parameterization allows to safe the entire building process repeat it on any figure with other parameters [8].

5.2 Application Tight Fitted Garments

This category of 3D virtual tools is mostly used for tight fitted garments which can be underwear, lingerie, swimwear, sportswear, medicine Products etc. For constructing close or tight fitted garments by using appropriate 3D CAD software, the intended design can be directly constructed on the virtual model, and the corresponding cutting patterns are automatically flattened into the plane [43]. 3D Pattern development for close fitted garments, step by step is shown in the flow chart presented in Figure 5.18 and process chain for tight fitted garments in shown in Figure 5.19.

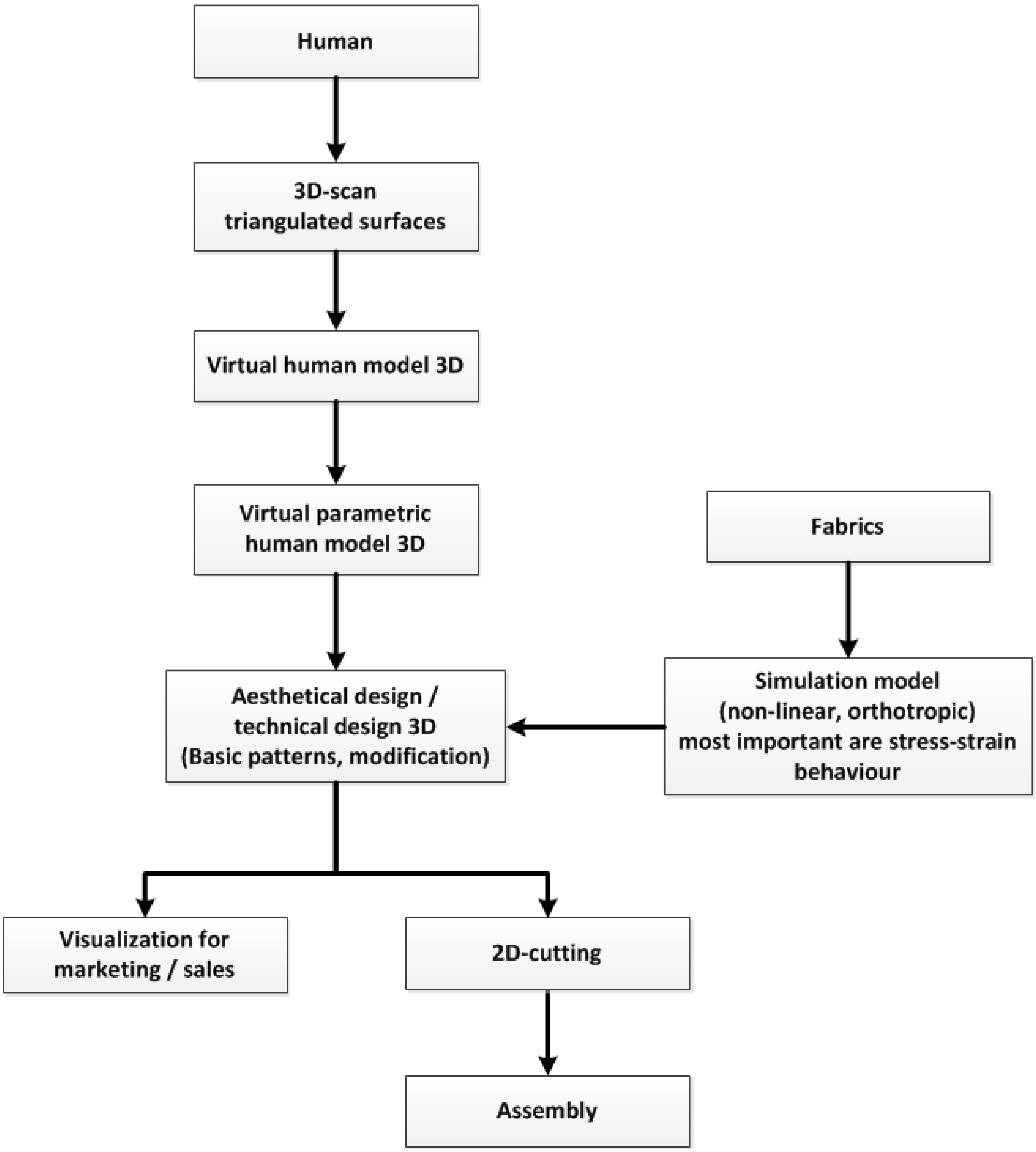

Figure 5.18: *Flow chart for 3D pattern development for tight fitted garments [28]*

Figure 5.19: *Process chain for tight fitted garments [28]*

The major potential underwear / lingerie products producers which use relevant 3D virtual tools are Triumph etc. Major producers of high functional sports cloths are Adidas, Nike, and Speedo etc. The main virtual 3D tools available for this category are explained as follows:

5.2.1 DC3D by LECTRA

This software is called as Design Concept 3D, it is provided by Lectra (France) and it is capable of executing 3D to 2D pattern unwrapping. It has been used experimentally for creating 3D virtual designs of close-fitting garments after customizing it with additional components [37]. DC3D is currently being promoted for use in car seat design and for technical textiles applications such as application textile reinforced lightweight structures and application textile packaging which is mentioned in Sections 5.3, 5.4 and 5.5.

5.2.2 PDS Version 11 by Optitex

Optitex PDS version 11 is a huge leap into a more user friendly, more advanced and easier to operate pattern design / grading and 3D system. The performance area is improved in this release of PDS version 11 by Optitex. In order to speed up the user actions and pattern design needs, a number of hotkeys are designed / added into this new version. New license management architecture is also introduced [58].

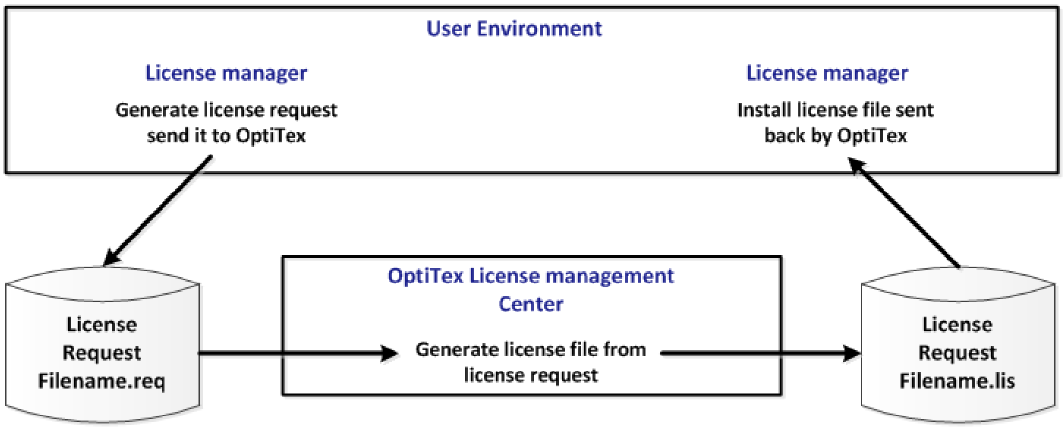

Figure 5.20: *New license management architecture in PDS version 11 by Optitex [58]*

This version provides users with an array of enhancements and new features including upgrade for windows 64 bit architecture, improved 2D tools in slash and spread functionality, walking capabilities, variation grading, 3D algorithm and GUI, and a new network protection system (SRM). The version 11 has also improvements in its 3D capabilities [52]. A fabric library can be created using a utility to define physical and visual properties or convert lab results to OptiTex standards. An OptiTex Fabric Editor allows the entry of lab results from the FAST and Kawabata systems for appropriately setting software fabric parameters. OptiTex also refers customers to a fabric testing machine for in house fabric testing [59].

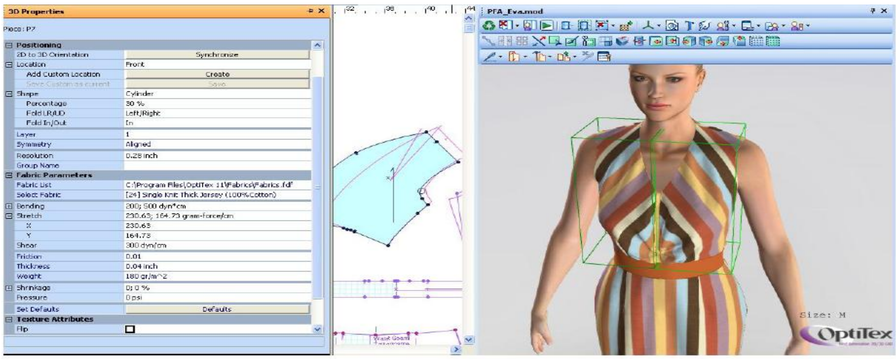

***Figure 5.21:** Fabric editor function in PDS version 11 by Optitex [59]*

For garments with many exposed stitches, appearance may be changed to better match actual stitching as shown in Figure 5.22, the jeans example using a picture file. The stitch appearance characteristics better represent the stitching on a real garment [59].

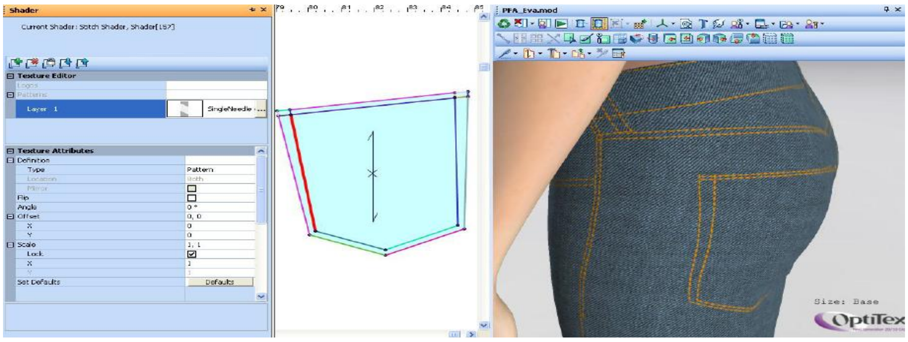

***Figure 5.22:** Changing the appearance of stitches in PDS version 11 [59]*

The algorithm field of Version 11 includes improved folding options for pre-simulation, better collision detection, rigid bending and improved physics. New multi-core parallel hardware capabilities are fully utilized accelerating simulation time dramatically. Examples are Intel® Core™ i7 Processor and NVIDIA CUDA™. The 3D Creator engine has been reworked to provide even faster simulation, improved accuracy of drape, decreased file size, and updated avatars with even more measurements. Furthermore, an array of 25 languages is incorporated into the program [52].

5.2.3 TPC 3D Interactive Software

3D Interactive software is another 3D software product from TPC (HK) Limited (Hong Kong). This software offers a 3D working environment for pattern designers. In order to convert 3D designs developed on a virtual mannequin automatically into 2D master slopers, this software provides and exploits 3D relational-geometry. The master slopers thus created are taken to those striped off from a 3D garment form, making the attainment of “best fit”. For real manufacturing scenario the system has the capability of facilitating the conversion of data to 2D. This software is shown in Figure 5.23 [37][60].

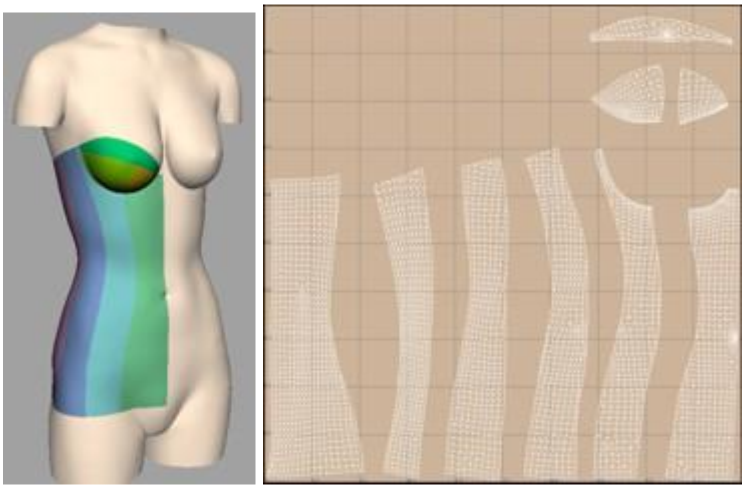

Figure 5.23: *Examples of 2D patterns (Right) from 3D Design using the 3D Interactive Software from TPC (HK) Limited [60]*

5.2.4 3D Runway Flattening Tool

The 3D flattening tool of the 3D Runway program offers the opportunity of extracting 2D pattern pieces from 3D design and its only limited to tight fitted garments. This software has on board a range of parametric mannequins to be used as 3D design platform. By the means of several posture positions and five adjustable body measurements, these mannequins can be customized. For viewing any design details in the form virtual clothing, there is a texture mopping tool available for this regard. This software according to OptiTex [52] can help to reduce the time to market and to minimize material wastage in the product development stage. 3D Flattening tool is shown in Figure 5.24.

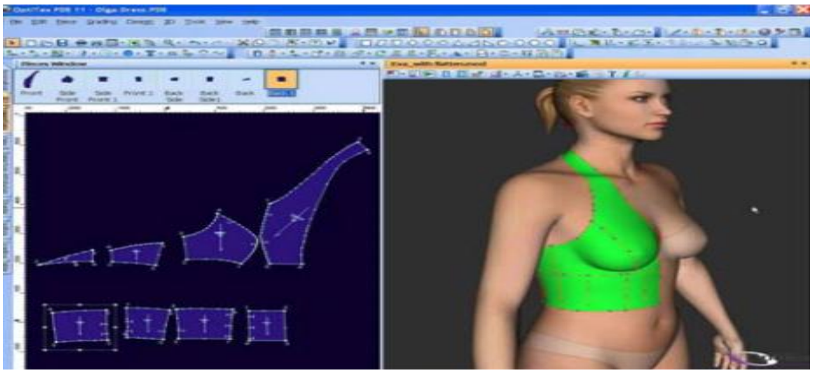

Figure 5.24: *Example of 2D patterns (Left) extracted from 3D Designs by the 3D Runway Flattening Tool [37][52]*

Furthermore, 3D Flattener's new technology enables on-screen transformation of three-dimensional objects' surface into two-dimensional patterns that make up the draped object [37][52][53]. This feature performed by 3D Flattening tool is shown in Figure 5.25.

Figure 5.25: *Draped object made from extracted 2D patterns by the 3D Runway Flattening Tool [37][52]*

5.3 Application Car Seats Cover Development

This category of 3D virtual tools is mostly used for the designing of car seat covers, cockpit, interior equipment etc. The major potential car manufacturers which use relevant 3D virtual tools are Audi, BMW, Daimler and Volvo etc. Major players of automotive supply industry which use 3D technology tools are Faurecia, Sitech, Lear Corporation and Johnson controls etc.

Figure 5.26: *Process chain for seat cover development [28]*

The usage of 3D virtual tools for the development of car seat covers has a major impact on the development time and cost. It reduces the time and cost and makes the process faster and cheaper with other many positive factors.

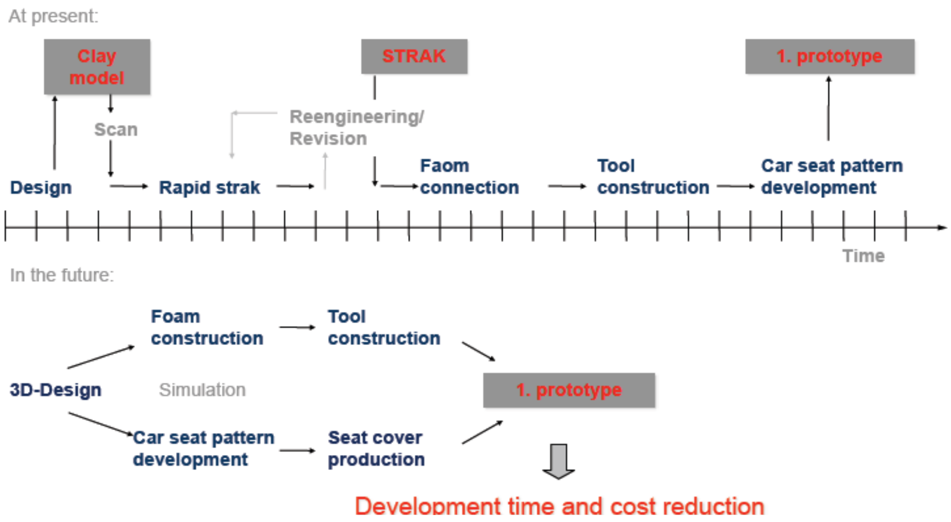

Figure 5.27: *Reduction of development time and process cost for car seat covers [28]*

The main virtual 3D tools available for car seat covers development are mentioned as follows:

1. DC3D by LECTRA.
2. PadMaker by CES-Eckard
3. Forming Suite by CAD-FEM
4. Seat design environment by VISTAGY(Siemens)

5.4 Application Textile Reinforced Lightweight Structures

3D virtual tools belong to this specific category are mostly used for the designing of textile reinforced lightweight structures such as boats, airplanes, helicopters, wind mills etc. The potential users of such 3D virtual tools are aerospace companies e.g., EADS, Boeing, Embraer etc and also some companies which belong to the automotive and manufacturing systems engineering such as BMW etc. The main virtual 3D tools available for this category are mentioned as follows:

1. DC3D by LECTRA.
2. CATIA, CPD by Dessault
3. Forming Suite by CAD-FEM
4. FiberSim by VISTAGY(Siemens)

5.5 Application Textile Packaging

This category of 3D virtual tools is mostly used for the designing of transport packaging for cars, car parts, instruments, valuable goods and goods with sensitive surfaces etc. The major potential producers of packaging means which use 3D virtual tools are

Knuppel Verpackung GmbH & Co, Freudenberg & Co etc. The main virtual 3D tools available for this category are mentioned as follows:

1. DC3D by LECTRA.
2. Forming Suite by CAD-FEM
3. PDS Version 12 by Optitex

6 CASE STUDIES DESCRIPTION

This chapter will provide a brief overview of chosen case companies and third party organizations, which were complied on the basis of findings, collected from interviews and internet sources. The overview of the case companies includes outlining the 3D virtual tools they are using for product development and management facilities. What is the selection criterion applied for these tools and also highlighting some of the challenges they are facing and how they are tried to overcome. The overview of the third party organizations includes education, seminars, network arrangements and other support they provide to the fashion companies for implementing 3D technology strategies.

6.1 Case Companies: 3D Technology Initiatives

This section on the case companies looks at the situation how the case companies are applying virtual techniques in their business and to which extent. The chosen case companies are from four different parts of the world, and a brief overview is given that how far 3D technology has been spread around the globe. An overview of fashion case companies can be seen in Table 6.1 on page 58 and the essential information of the case companies is described here.

6.1.1 Adidas

Adidas is a very popular and large sports company based in Germany. Adidas is one of the leading sports company to implement virtualization technologies in all departments of the organization form product designing, marketing, sales and sourcing since 2009. Virtualization has been a strategic initiative for the Adidas group since 2004 when the first technology research was conducted by looking into how the automotive and aerospace industries were successfully showing their products using 3D digital technology. In 2006, a department responsible for virtual creation technologies was founded, which started working on how to create photorealistic images of footwear and apparel in 3D that could be the integral part of the Adidas group’s product and sales engine.

In 2009, the start of the 3D process implementation began and initially it was not easy process for the Adidas group because of two main challenges which were faced. First, as sports good are made of soft surfaces, and thereby draping and complex texture problems were faced. Secondly, Adidas group produced thousands of different articles per year and for this they needed to create 3D models for every model and color way on time and in the right quantity.

Renate Eder (Team lead, creation technologies Adidas group) mentioned in her interview that Adidas group is using different software's provided by different software providers for different product categories. For instance, for apparel they are using 3D software provided by Browzwear and according to her, it is the most adequate tool for mass production of 3D garments. Browzwear software is not too complex to use as well, it has a good aligned vision and strategy and this was the reason for the selection of this specific software. For footwear technology, Adidas is using 3D software's provided by Modo, Rhino, RTT Deltagen, because they have real-time and rendering quality and versatile modeling possibilities. For bags, they are using 3D software provided by Optitex, since this software has the best bag simulation compared to the other software's available in the market.

According to Renate Eder, some of the main technical challenges faced by them while using these 3D tools include visual quality problems, ease of use, speed of usage, and acceptance of software. These challenges are being overcome by following ways: the quality department is working on constant quality improvements to minimize visual quality problems; and software providing companies develop Adidas specific user interfaces that help in making the software usage easy. Adidas constantly works with the software vendors on performance topics, and the process performance is taken care of as well to increase the speed of software usage. The 3D process completely changes the way of working thus change management, the trainings are conducted for the designers and other personals using 3D software's as it is one of the most important steps to make the software accepted internally.

Renate Eder said that the immediate benefit of virtualization is that it allows to increasingly reducing the quantity of physical samples required to design and sell new products. Because of virtualization, Adidas have been able to save more than 1 million physical samples from 2010 to 2013. Further highlighted by her, with virtualization they save resources and money by reducing material waste, transportation and distribution costs and with fewer samples being flown around the globe and they are reducing their carbon emissions. Because of all these benefits today (2013), Adidas group has seasonal production of 13.000 virtual products per season (Spring/Summer and Fall/Winter).

6.1.2 Comercializadora Arush

A women's apparel manufacturer based in Mexico, Comercializadora Arush was founded in 2005. Since then the company has supplied the Mexican market, ranging from large retail outlets such as Wal-Mart and Suburbia to a variety of smaller stores with clothing of all sizes ranging from junior to extra large. Arush is also the women's apparel licensee for Pierre Cardin in Mexico. Currently, Arush has approximately 220 employees and makes around 120 styles per month. Designers at Arush work in two different ways, for retail clients Arush designers work closely with the designers of the client companies to create collections in a collaborative environment according to the demand and requirements of the clients; while for Pierre Cardin and some retail clients Arush is presented with trends and general guidelines for a collection for each season and its designers create all the styles from scratch.

Arush is the first North American company to implement Lectra's 3D design prototyping software, and has experienced that virtual models reveal any problems with fit, long before even a sample is made. The founders of Arush had experience of using Lectra software from their previous firms and when they launched Arush, they decided to build on that successful experience. Therefore Arush has been a Lectra shop from the beginning and uses many software applications from Lectra's design and development suite of tools.

Kaledo Style is used for conceptual design for example choosing color palettes, sketching styles and creating style boards to interest buyers. Arush uses Lectra's Modaris software for pattern making and DiaminoFashion software for interactive and automated marking with the help of automatic spreader and two automatic cutters in order to make samples for buyers to review. Several months ago, Arush in quest to make more fewer, more accurate samples tested the latest version of the Modaris, Arush is Lectra's first North American customer to implement this technology, which features 3D prototyping capability. Arush is also ready to consider implementing a product lifecycle management (PLM) solution also from Lectra. Because Lectra products are all compatible with one another, styles can be sketched in one program, designed in another and displayed or modified in a third, giving designers new vistas for their creativity.

At Arush, one of the problems which was faced while using Modaris was that: with the 3D feature, a patternmaker designs a pattern in the usual way which is in two dimension, and then views a three dimensional representation of the garment on an on screen avatar. In order to look at the avatar from all angles and in different positions by the patternmaker and the designer, the avatar can be rotated on screen. Often problems with fit become apparent when a pattern is viewed in three dimensions, even when the initial sketch appeared flawless. To resolve the problem, the designer can work with the patternmaker to make necessary adjustments to the fit before the first sample is ever produced. Most of the companies have the goal to produce a first sample which is as close as possible to the final product [61][62].

6.1.3 ICICLE

ICICLE is china's leading eco-friendly fashion brand. This company was formed in 1997 and it is based in Shanghai. It is one of the most respected brands in China selling womenswear, menswear, infants and children's clothing through more than 100 franchised and branded shops across China. It launches new collections spring/summer and Autumn/Winter. As being a quality brand for china's customers; ICICLE imports high quality natural materials from all over the world including cotton from Japan and knitted fabrics and wool from Italy. The company also uses high-end cotton, bamboo and silk produced in China.

ICICLE has its own designers, technical designers and pattern makers. It manufactures products in its own factories and manages logistics as well as distribution to retail stores. For efficiencies in pattern design, technical design and sample making ICICLE is using Gerber's AccuMark pattern design, grading and marker making software since 2006. According to general manager and design director of ICICLE Ye Shouzeng [63], ICICLE selected Gerber's AccuMark software because of their leading position in the fashion industry.

To counter fierce market competition ICICLE invested in bringing to market high end product lines that had intricate and unique designs, material and construction details. The challenge which was faced by ICICLE was that in order to replicate success of the products released in the past the team of designers needed to leverage past digital assets in the company. But most of the digital assets and past details were not available in a central location and it took them longer time to manage the product design. Therefore, ICICLE decided to use the Gerber's YuniquePLM by this ICICLE was able to take advantage of its expansion library of technical drawings, style images and material images to promote collaboration and stay ahead of the design curve [63][64][65].

6.1.4 Delta Galil

Delta Galil based in Israel and is a global manufacturer and marketer of private label apparel products for men, women and children. It was founded in 1975 and has become a leading innovator in next to skin wear by transforming itself from a small local garment producer to a global organization.

The company expended strongly in the 1990s and 2000s, resulting in a substantial increase and establishing product design, development and manufacturing centers on four continents, employing 7000 people worldwide and serving 50 industry leading customers in the US, UK and continental Europe i.e., Marks & Spencer, Target, Wal-Mart, JC Penney, and leading fashion brands such as Calvin Klein, Nike, Hugo Boss etc. Delta Galil also sells its products under brand names which are licensed to the company, including Wilson, Maidenform, Tommy Hilfiger and others. Delta Galil has its own professional designers, who work together with the clients designers to help introduce new products and innovative manufacturing solutions that answer consumer demand and help grow their market share.

According to Esti Maoz, Delta's corporate SVP, in the expansion phase of the company in 2000, the company was facing problems of product design and development as there was gap of external and internal communication between designers, pattern makers and sample room as each of them are located in a different place. Because of this the produ-

Table 6.1: *Overview of fashion case companies*

Company	3d tech, Start year	Product category	Firm Dimension	Nr. of virtual tools used	Selection criteria
ADIDAS	2004	Apparel sportswear, Footwear & Bags.	Large	Browzwear for Apparel.Modo, Rhino, RTT Deltagen for Footwear. Optitex for Bags	Based on the technical features suitability
COMERCI-ALIZADO-RA ARUSH	2006	Apparel for Men, Women & Children.	Small	Kaledo Style, Lectra's Modaris, DiaminoFashion	Based on the previous experience
ICICLE	2006	Womenswear, mens-wear, infants and children's clothing	Medium	Gerber's AccuMark, Gerber's YuniquePLM	Virtual software providers strength of core technologies with 3d tool
DELTA GALIL	2004	Private label apparel products for men, women and children.	Medium	Browzwear V-Stitcher	Leading position of software pro-vider

ct development and design cycle, time was also increased and as a result the cost was also increased. Therefore, the company decided to start the use of Browzwear V-Stitcher 3D garment design and visualization software with a pilot implementation at its innerwear division and in 2004, the first phase of its installation was completed. The results of this limited project were “very encouraging” said Esti Maoz, because of this the number of in process samples were reduced significantly. The product development and design cycle time was consequently decreased and the external and internal communications were improved between these facilities [66][67][68].

6.2 Third Party Organizations: Initiatives and Support

This section on third party organizations looks at their initiatives and support provided in different forms to the fashion companies for going forward towards 3D. An overview of third party organizations can be seen in Table 6.2 on page 62 and are further described in detail here.

6.2.1 MIRALab, University of Geneva, Switzerland

MIRALab is an interdisciplinary research laboratory at the University of Geneva, which was founded in 1989 by Professor Nadia Magnenat-Thalmann. This lab is composed of senior researchers, PhD and MSc students, designers and administrative staff. The research is done in the fields of visual humans, virtual worlds and multimedia technology.

Since its foundation, MIRALab has participated in more than 40 research projects, either European or Swiss national projects and helped the fashion and other industries in many ways to go forward towards 3D by presenting its live interactive high-tech shows at international events such as the word largest technical fair CeBIT, in Hannover and many more. It has also presented numerous research papers at top conferences and published several papers in journals and proceedings; for instance the research project Haptex which was related to the core issue of 3D technology, haptic sensing of virtual textiles was presented in Cyberworlds 2007 conference in Hanover, Germany, on October 24, 2007. In this conference, many people from the fashion industry as well as students were trained by arranging workshops on haptic sensation of virtual textiles [69].

6.2.2 CAE Laboratory, Technical University of Dresden, Germany

The CAE laboratory at TU Dresden is the only university research centre in the field of textile and readymade technology that possesses versatile software for product development of clothing and technical textiles. For design as well as for the constructive realization of drafts, modern 2D and 3D software solutions are available for research and training.

The main function of lab of the institute is providing a high quality curriculum to students and on research activities with the following objectives:

- Conducting fundamental research activity and industry oriented projects.
- Continual expansion of interdisciplinary cooperation with research institutes in various 3D disciplines and industry partners.
- Transforming the research results into practical solutions by providing new virtual tools.

The laboratory has been upgraded in recent years with extensive investments in CAD programs such as DesignConcept, 2D and 3D Modaris ExpertPro, Modaris 3D Fit and Diamino etc. The research activities concentrate mainly on the development and implementation of highly 3D innovative methods for product development. For instance, a research of the integration of material properties of the textile fabrics, semi finished material for product simulation and the development of suitable measuring technology was successfully completed at the lab [70][71].

6.2.3 Council of Textile and Fashion Industries of Australia (TFIA)

TFIA was established in the late 1940s when the Textile Council of Australia was formed as an organization to provide a focal point for big, medium and small sized SMEs in the textile, fashion and footwear industries. A textile and fashion hub is created where the SMEs can easily access resources, knowledge, leading edge equipment, capital and experience.

The textile and fashion hub is all about increasing the capability of the textile and fashion industry by providing industry specific trainings, seminars and workshops such as a series of six workshops were conducted by the name of Fashion design-CAD patternmaking using Lectra, which covered range of valuable and creative objectives. It arranges regular networking events and exhibitions, which often are connected to large industry events. For promoting and providing support for the 3D technology, the hub has a fully equipped CAD room, digital garment printer and Spacevision Cartesia 3D body scanner. The hub also has seminar rooms with touch screens, a production room, show rooms and a resource library.

TFIA has introduced a network of clusters consisting of industry professionals, in order to make recommendations on equipment needs, trainings and for addressing issues openly and finding the solutions to these issues by working together on the projects. Current clusters groups include product safety, labeling and standards, performance wear, manufacturing and most importantly design [72][73].

6.2.4 Productivity and Design Development Centre (PDDC) & Virtual Garment Centre (V.Gc), Singapore

Because of many garment manufacturers moved their fabrications abroad, Singapore's textile and apparel industry has converted to a regional marketing and sourcing hub. The textile and Fashion Federation of Singapore (TaFf), with many other objectives has set an objective to put up a platform for Singaporean designers and brands to exhibit and sell their designs.

In order to achieve these objectives and strengthen the complete industry, TaFf has built 2 key initiatives: The Productivity and Design Development Centre (PDDC), the Singapore Fashion Week (SFW) and the Virtual Garment centre (V.Gc). These are working together in order to provide mass adoption of 3D technology in product development. It is expending the industry design capacities, developing industry technologies with the help of virtual softwares and providing training to the industry engineering experts, these are some of the tasks of PDDC and Virtual Garment Centre [74].

Table 6.2: *Overview of third party organizations*

Organization	Country	Type	Purpose	Resources / Support	Members
MIRALab, University of Geneva	Switzerland	Research institute	Conducting research in the fields of visual humans, virtual world and multimedia technology.	Participation in more than 40 research projects, publishing and presenting papers in conferences.	Researchers, students, designers
CAE laboratory, Technical University of Dresden	Germany	Research institute	Research on the development and implementation of highly 3D innovative methods for product development.	Cooperation with research institutes in various 3D disciplines and industry partners and provision of new tools.	Different research institutes, companies, designers etc.
Council of Textile & Fashion Industries of Australia (TFIA)	Australia	Network organization	Fashion hub where the SMEs can easily access resources, knowledge, leading edge equipment, capital and experience.	Providing industry specific trainings, seminars and workshops.	Textile and fashion companies
Productivity and Design Development Center (PDDC) & Virtual Garment center (V.Gc)	Singapore	Network organization	Platform for Singaporean designers and brands to exhibit and sell their designs.	Expanding the design industry capacities by providing training to the industry engineering experts.	Fashion companies

7 EMPIRICAL FINDINGS

This chapter aims to highlight some of the essential elements regarding 3D virtual technology, derived from the interviews, software providers, research institutes and also internet sources.

7.1 Trends & Demand in the Fashion Market for 3D Virtual Tools

The virtual clothing technologies propose to innovate and benefit the apparel design and manufacturing landscape in many ways. Agents, product managers, designers, pattern makers and lately consumers benefit from virtual technologies like garment collection planning, digital editing processes, 3D body scanners, 3D modeling of garments, simulation and visualization etc.

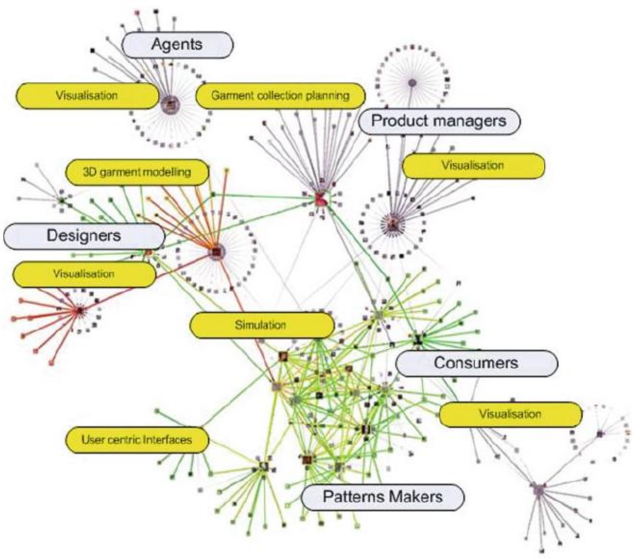

Figure 7.1: *Actors who benefit from virtual clothing technologies [32]*

Virtual clothing technologies have provided an added value to the fashion industry on the one hand by providing novel production paradigms, such as “Virtual prototyping” and “Virtual Try on”, and on the other hand by integrating the user deeper into the design and the operation of the garment manufacturing process through online collaboration platforms. However, today the clothing and fashion industry is still taking a limited advantage of the existing virtual clothing technologies to satisfy the current trends to varying degrees [32]. According to Renate Eder (Team lead, creation technologies Adidas group), the trend towards 3D technology is changing and nearly every fashion / sports company is at least starting to evaluating the potential of 3D, especially in Europe and now this is spreading around the globe as many of Adidas core factories are trained and now are capable of producing high-quality volumes of virtual samples. According to Browzwear, their software V-Stitcher is implemented at 150 companies in more than 30 countries [75].

A report shows that the European companies, who have tired 3D prototyping feature, have provided a feedback that it reduces the number of samples they require by about 50 percent, which saves fabric and modeling expenses and allows them to bring new styles to the market faster. It was mentioned by Renate Eder that because of virtualization they have been able to save more than 1 million physical samples from 2010 to 2013. Similarly the director of production and planning at Arush, Isaac Gershevich says that the eliminating the production of one sample for each style could save Arush between $10,000 and $15,000 per year and most importantly would save a day or two off the product development cycle for each style. Arush produces its samples in-house and for the companies whose samples are produced off-site, by eliminating a single sample could shorten the product development cycle by as much as six weeks [61][62].

7.2 Criteria for Selection of 3D Software Providers

The selection process of 3D software of designing and managing products, for the company can be hectic as there are many suppliers of the 3D softwares having almost similar technical features to each other. The interviewed fashion companies have applied a number of criteria, i.e., offering of best technical features, company personnel having previous experience with the software usage, due to the leading position of the software provider in the fashion industry, and also if the advance system integrates well with the new system – eliminating a lot of redundant work .

At Adidas, the criteria applied for the selection of 3D software is mostly based on the technical features offered by the software for instance simulation options, modeling possibilities, real-time and rendering quality features, suitability for mass production of 3D garments, easy to operate, good vision quality and strategy. The founders of Arush had experience of using Lectra software from their previous firms and when they launched Arush, they decided to build on that successful experience. Therefore Arush has been a Lectra shop from the beginning and uses many software applications from Lectra's design and development suite of tools. Based on this experience, Arush is also ready to consider implementing a product lifecycle management (PLM) solution from Lectra as well. Since, Lectra products are all compatible with one another, styles can be sketched in one program, designed in another and displayed or modified in a third, giving designers new vistas for their creativity. ICICLE selected Gerber's AccuMark pattern design, grading and marker making software due to their leading position in the fashion industry. ICICLE started using Gerber's YuniquePLM, because their pattern design system is also provided by Gerber and it integrates well with their PLM system, eliminating a lot of redundant work for them. Delta Galil decided to use Browzwear V-Stitcher 3D garment design and visualization software with a pilot implementation at its innerwear division because of the reputation of the software provider in fashion industry.

7.3 Challenges faced by the Fashion Companies while using 3D Virtual Tools

There are many challenges which have to be dealt with while using the 3D virtual tools. The following challenges have been mentioned by the experts who have been interviewed: technical problems faced i.e., simulation problems, visual quality; ease of use, speed, acceptance and no availability of previous technical design details is also a challenge faced.

At Arush, often problems with fit become apparent when a pattern is viewed in three dimensions, even when the initial sketch appeared flawless. To resolve the problem, the designer can work with the patternmaker to make necessary adjustments to the fit before the first sample is ever produced. To bring very intricate and unique designs, material and construction details. The challenge which was faced by ICICLE was that in order to replicate success of the products released in the past, the teams of designers were not able to leverage past digital assets in the company. As most of the digital assets and past details were not available in a central location and it took them longer time to manage the product design. Therefore ICICLE decided to use the Gerber's YuniquePLM alongside the Gerber's AccuMark Software.

According to Esti Maoz, Delta's corporate SVP, in the expansion phase of the company in 2000, the company was facing problems of product design and development since there was a gap of external and internal communication between designers, pattern makers and sample room as each of them are located in a different place. Because of this, the product development and design cycle time increased and as a result the cost was also increased. Therefore, the company decided to start the use of Browzwear V-Stitcher 3D garment design and visualization software. Cloth is highly deformable by nature and due to this clothing property specific simulation problems arise. Furthermore, the garment cloth interacts strongly with the body too that wears it as well as with the other garment of the apparel. Due to some of these challenges such as nonlinearities and large deformations occurring at places like wrinkles and folds in the cloth, are faced in mechanical representation of the cloth [32].

7.4 Other Organizations Support

One of the major factors to develop 3D technology and implement it in the fashion industry is being achieved by the role of the software providers, research institutions, textile associations etc, in supporting the fashion companies in implementing 3D technology. These organizations have a large expertise within 3D technology aspects applied to the fashion industry. Their pivotal role consist of being able to provide the need assistant to the companies that are in the initial start-up stage to launch implementation of 3D technology and also to the fashion companies that has already experience of working with 3D technology. The case companies have expressed the support from third party organizations (e.g., software providers, research institutions, textile associations etc) can help with the challenges related to 3D virtual technology. These forms of support have been mentioned: conducting heavy research on 3D virtual issues, producing new softwares, providing different 3D educations, trainings and 3D seminars.

Different education, trainings and seminars was mentioned by most of the respondents as something that should be offered in a large extent to the fashion companies, not only to those who are already working with 3D virtual technology in their company, but also to those fashion companies who want to initiate it. This can advance the company in the field of product designing and managing, but also make the company see the new opportunities that they did not know existed. These organizations have a large expertise within 3D technology aspects applied to the fashion industry. The support provided by third party organizations includes research and seminars on issues concerning with for instance haptic interaction modalities with virtual cloths by MIRALab [69].

As expressed by Sharon Lim, Managing Director at Browzwear, that people should be educated about 3D Technology in the fashion industry as ”*Mostly fashion companies have zero knowledge of 3D Technology and that is the reason they think it’s complex and difficult*”. Isaac Gershevich, director of production and planning at Arush, says the pattern makers at the company have been trained by Lectra to use the new 3D software and are now fully proficient. The designers however have only been through introduction course and Arush expects to spend more time training them. Though the pattern-makers do the work of prototyping, designers need to be able to make decisions based on what they see on the screen. But after going through a few follow-up training sessions provided by Lectra experts, the designers normally are comfortable enough to use the system.

8 ANALYSIS

Based on the information collected from literature analysis, available virtual tools, case studies, interviews, third party organizations and internet, this chapter aims to provide an analysis according to the thesis methodology framework introduced in Section 2.2.

8.1 A Comparison of the Available 3D Designing Systems

As discussed by Winsborough, 2001 and Yan, 2007 [36], there are three mutual connected tasks being solved when 3D apparel designing systems are being developed: the development of a virtual mannequin, the creation of a 3D shape of a garment model and the 2D layout of the details. For these tasks there are two possible sequences used by different software systems, i.e., Optitex CAD system that imitate garments, use 2D templates that are sewn together virtually. In its turn 3D designing systems create the surface of a garment in relation to a mannequin and acquire the layout of details afterwards like Staprim CAD system. According to Szabo, 2008 [36], the correct set of a garment and the visual perception of a model are influenced by the placing of parts of the garment onto a 3D mannequin. For the perception and evaluation of an apparel model, the visual qualities of a fabric like color, pattern and texture are considered very important.

The comparison Table 8.1 on the next pages examines the most well known available 3D designing systems which offer 3D designing: Optitex (Israel), Staprim (Russia), Lectra (France), Assyst (Germany), Gerber (USA), Assol (Russia) and Bernina (Switzerland). The comparative table shows that despite the fact most of the virtual systems strive to use some of the 3D designing and fitting stages, most of the systems are made for 2D pattern fitting; whereas the actual indication of 3D designing would be the creation of garment pattern on the surface of a mannequin and defining ease allowances by setting projection space between the garment and mannequin [36].

By benchmarking all CAD systems provided by various companies available in the market, it can be analyzed that a few year ago most of the designing tools have been almost the same. They were more or less identical to each other, because all of them computerize the same or almost similar plane like methods for creating patterns of cloths. Although, in available different virtual designing systems for layout of patterns there are some distinctive features between the systems, but they are never long-term considering the constant development of the software of all companies.

Table 8.1: *Comparison of the available 3D designing systems [36]*

#	Parameter		Description	Optifex	Starprim	Lectra	Assyst	Gerber	Assol	Bernina
1.1	**MANNEQUIN**	Sex	Feminine one type	×	×			×	×	×
1.2			Feminine several types			×	×			
1.3			Masculine	×		×	×	×		
1.4		Parametric		×	×	×	×	×	×	×
1.5		Individualization	Traditional measurements	×	×	×		×	×	×
1.6			Projection measurements		×					
1.7			Integration from 3D scan			×	×	×	×	
1.8		Imitation of movements	Virtual movement	×						
1.9			Change of current posture			×	×	×		
2.1	**CREATION OF GARMENT SHAPE**	Designing of apparel parts on a 3D mannequin		×					×	
2.2		Definition of an intermediate layer (ease allowance)	Projection distances		×				×	
2.3			Traditional ease allowances		×					×
2.4		Usage of finished apparel parts	3D construction templates		×				×	×
2.5			“Sewing” and “try on” using 2D templates	×		×	×	×		

Table 8.1: *Comparison of the available 3D designing systems contd. [36]*

#	Parameter	Description		Optifex	Starprim	Lectra	Assyst	Gerber	Assol	Bernina
3.1	**CORRECTION OF GARMENT SHAPE**	In plane, checking 3D		×		×	×	×		×
3.2		3D, automatically changes in plane		×		×	×	×		
3.3		Changing numerical parameters			×		×		×	×
4.1	**VISUAL CHARACTERISTCS OF A GARMENT**	Fabric characteristics	Elasticity	×		×	×	×	×	
4.2			Drapery	×		×	×	×	×	
4.3			Structure	×		×	×	×	×	
4.4			Stiffness control			×	×	×		
4.5		Individualization	Color / pattern	×		×	×	×	×	×
4.6			Size of pattern			×	×	×	×	
4.7			Texture			×	×	×	×	
4.8		Placement of decorative elements		×		×	×	×	×	×
5.1	**EASE CONTROL**	Color code		×		×	×	×		
5.2		Numeric evaluation		×	×	×	×	×		

There are some differences in the choice of toolkits as solutions of the some part of the system, but in some period of time similar solutions appear on other systems. The major difference is maybe the price policy offered by different companies and also the technical support offered at different levels can be considered as a difference. However, now the companies realize that it is not sufficient to have similar technical CAD tool as being offered by other companies and they start to specify and develop in various areas. Some start to be more attractive for designers. Additionally, a good visual quality was not really achieved in the past, but now a few companies invest into that. Furthermore, there are a few "newcomers" like Clo3D Marvelous Designers who modernize the offer of 3D tools. However, a comparison of the tools is impossible and each has its own strengths.

8.2 Cross-case Comparison of 3D Technology Strategies

Based on the case studies and empirical findings, the cross-case comparison of fashion companies virtual technology strategies is structured according to the following issues:

- Virtual technology trend
- Criteria applied for the selection of 3D technology suppliers
- Challenges faced with 3D technology

A special feature of the fashion industry is that it affects consumers with the latest trends every season and thereby, makes other cloths and accessories unfashionable and needless. These fast moving fashion trends promote the use of 3D virtual technologies by the fashion companies in order to achieve countless benefits for instance:

- Saving of physical prototypes
- Saving of salesman samples
- Saving of photo shooting sample
- Saving photo shooting cost
- One file serves many application areas (development, marketing, sales)
- Easier communication (less misunderstandings / feedback loops in the product creation phase) and collaboration
- Early product previews
- Early decision making (e.g., on product designs)
- Fast product (image) update
- Automation possibilities due to digital product data.

Because of all these above mentioned benefits of 3D technology, the trend for virtual technologies usage in the fashion industry is very demanding and almost every fashion \ sports company is at least evaluating the potential of 3D technology. As discussed before that the software V-Stitcher provided by Browzwear is implemented at 150 companies in more than 30 countries, from this it can be analyzed that the trend of virtual technology usage has been spread around the globe. An analysis is done based on the case study and interviews conducted with the case company representatives, and it is revealed that the 3D technology has started to be used around the globe as Adidas, ICICLE, Delta Galil and Comercializadora Arush come from different parts of the world. Excluding Adidas as it is a huge fashion sports company, other companies studied are medium or small sized fashion companies that gives an empirical evidence that even small sized companies like Delta Galil and Comercializadora Arush are moving towards the virtual technology world.

Case companies have applied number of various criteria to select their 3D software provider. These criteria are usually applied differently, if the company is producing different product categories or types, for instance Adidas is producing apparel, footwear and bags, which are three different types of products. They applied different criteria for choosing virtual softwares for these products. For the apparel category, they needed most adequate tool for mass production of 3D garments. According to Renate Eder, they are producing around 13,000 virtual garments per season (Spring/Summer and Fall/Winter), and they needed a software which is not too complex to use and most importantly has an aligned vision and strategy. After benchmarking all the available tools, Browzwear was meeting their criterion and they started to use this Browzwear software for their apparel section. For footwear, they chose Modo, Rhino and RTT Deltagen softwares since they were meeting their criterion i.e., real-time and rendering quality and modeling possibilities. For bags, they needed software which provided best bag simulation opportunities, and Optitex bag software provided by Optitex was selected as this provided the best simulation possibilities compared to its competitors.

The interviewed case company Arush, in order to reduce the risk of trying a new software system provider and avoid time and money loss, they selected a virtual software provider on the bases of the previous experience of using the software by the founders of the company, and they selected the virtual software provided by Lectra to build on that successful experience. For selecting a product life cycle management (PLM), Arush is following the same criterion i.e., the previous experience of using the system and are planning to select the PLM software provided by Lectra. Other case companies have implemented the criteria for selecting a software provider on the bases of the leading position, and good reputation of the software provider in the industry and continued using its other software systems as in order to eliminating a lot of redundant work for them in trying a new software provider.

In implementing 3D technology strategies and using virtual tools, case study fashion companies faced a number of substantial challenges. As earlier mentioned, challenges lies in technical problems faced i.e., simulation problems, visual quality, ease of use, speed, acceptance and no availability of previous technical design details is also a challenge. While using 3D technology, some case companies faced technical challenges such as visual quality problems which were tried to overcome by the working of different departments on constant quality improvements. Ease of use of the software is also a problem faced, which is minimized by companies developing specific user interfaces. The speed at which the software can be used is a technical problem faced in some of the case companies that is constantly improved by working with the software vendors on performance topics and also the process performance is also be taken care of. The acceptance of the software in some of the companies was a challenge faced as well, since the 3D process completely changes the way of working. Thus, change management and training are one of the most important topics to reduce such challenges like this.

8.3 The Role of Third Party Organizations in Supporting Fashion Companies in implementation of 3D Virtual Technology

Third party organizations have tools and resources to help fashion companies to implement 3D virtual technologies in product development, management, sales and marketing. Third party organizations contribute to fashion companies' ability to implement 3D tools and techniques by:

1) *Offering Trainings / education*. Software providers offer different training sessions and education for different fashion companies using the software provided by them or general trainings for software users as well as for researchers. In addition, research institutions conduct research on new issues of 3D technology which not only educate the software providers, but also provide knowledge for the 3D technology users for instance research project conducted by MIRALab on issues concerning with haptic interaction modalities with virtual cloths, which provided an knowledge platform for the software designers and users, how to overcome issues related to sensation of feeling the virtual garment [69].

2) *Network arrangements*. Research institutions and textile associations offer different network arrangements by conducting different seminars where software providing companies and user companies gather in order to share knowledge about each other experiences and dilemmas e.g., Design Modeling Symposium Berlin arranged by University of Arts Berlin since last several years. The latest 4th symposium was conducted from 28 September till 2nd October 2013 in Berlin, where many 3D software providers, users and researches as well as students participated. This symposium consists of two days of workshops and master classes and followed by a three day conference with keynote lectures, case studies and poster sessions.

3) *Up-dating news on virtual technology trends in the fashion industry*. Third party organizations as well as some of the fashion companies provide publications and

news about virtual technology trends in the fashion industry. These include information about new innovative developments in 3D virtual technology e.g., a blog page run by Adidas [76] on which latest topics regarding virtualization and other issues are discussed by their expert's. One of the important topics includes virtualization: creating and selling products in a sustainable way, by Renate Eder (Team lead, creation technologies Adidas group).

9 CONCLUSION

9.1 Main Findings of Research

Based on the analysis of the collected empirical data, the following answers on the posed research questions were revealed.

RQ1**:** What virtual product design, product development and management opportunities there are in the fashion industry?

The situation at the moment in the fashion value network in respect to virtual product development and management: In the fashion industry, there is a high competitive environment. Major brands, producers and retailers are evolving in a competitive environment where speed, quality and price are the main criteria. In building client loyalty and choosing an industrial partner, fashion companies need to be flexible, quick reacting and productive. The usage of virtual technologies, obstacles like time and distance are being minimized for collaborations among fashion companies when they are creating a collection. Fashion companies are going to the phase where they are developing complete confidence in solutions provided by 3D technologies on issues of brand image, renewal and cost optimization.

Virtual product design solutions and techniques (CAD) available in the market: There are a high level of virtual design solutions and pattern making systems. These systems provide the possibilities to eliminate manual work and small operations, to raise precision, productivity and organize information flow. These virtual designing systems make it possible to exclude the time consuming manual preparation of patterns, creation of layouts and relocation of written information. The 3D systems are meant for the execution of every single process and the integration of all the processes into one joint flow, for the organization of logistics and the mobility of work tasks. These computer systems allow making two dimensional as well as three dimensional product illustrations and visualizations. With the help of 3D computer systems, it is possible to create computer aided garment constructions, as well as gradations, and create a virtual first pattern of the model. These mentioned computer aided operations significantly decrease the time consumption and cost necessary to design a product. The cost itself can be calculated with the help of product management systems following the development parameters, the layout of patterns, textile expenditure, model complexity and specification as well as with the previous experience of the company stored in the data base.

Nowadays the CAD systems provided by various companies are not so identical: By benchmarking all relevant 3D tools available in the market, I must say that a few years ago most of the tools have been the same. However, now the companies realize that it is not sufficient to be a similar technical CAD tool as provided by other companies, and they started to specify and develop in various areas. Some of them start to be more attractive for designers. Additionally, a good visual quality was not really achieved in the past, but now a few companies invest into that as well. Furthermore, there are a few “newcomers” like Clo3D Marvelous Designers who modernize the offer of 3D tools. However, a comparison of the tools is impossible and each has its own strengths.

RQ2: How fashion companies are currently applied virtual techniques in their businesses around the globe and what are the selection criteria for these tools, what challenges they are facing?

Trend of Virtual technology usage by fashion companies is changing, but still slow and low: Before three decades, the trend for virtual technology usage in the fashion industry was almost zero, but now it has been changing as many fashion companies have started to at least evaluate the potential of virtual technology usage. Thanks to E-commerce, digital interactive selling, now there is definitely a greater pull for 3D virtual tools. Furthermore, the maturities of some tools with better user interface have prompted further use of it. However, it is still the tip of the iceberg. There is a greater push and pull as compared to the last decade and seen with less “suspicious”, but the adoption rate is still slow and low. An estimate of about somewhere around 500-1000 fashion companies around the globe are experiencing 3D. Some fashion companies from Europe, who have mass production of virtual garments, have implemented 3D technology in every operation of the organization; while the small and medium sized companies are at least experiencing virtual software usage in initial stages. Virtual technology usage trend is spreading to the third world as well, as most of the core factories of the fashion companies are in Asia and where mostly production of the final products takes place. Some of the core factories are trained and made capable of producing high-quality of virtual samples.

Selection criteria of virtual designing tools are different for different fashion companies: Criteria applied for the selection of 3D virtual software’s is deferent for different fashion companies, but for most of the companies it is based on the virtual software provider’s strength of core technologies with 3D tool. For large size fashion companies which are producing thousands of virtual products per season, their selection criteria for obtaining a virtual software is mainly based on the technical features offered by the software e.g., simulation options, modeling possibilities, real-time and rendering quality features, suitability for mass production of 3D garments, easy to operate, good vision quality and strategy. Some small sized fashion companies when implementing 3D virtual technology follow the previous experience of their founders with the software usage and prefer continuing with the same software as selected by the company founder because of having usage experience and knowhow of this software. Some fashion companies implement the criteria for selecting a software provider on the bases of the leading position and good reputation of the software provider in the industry, and continue using its other software systems as in order to eliminating a lot of redundant work for them in trying a new software provider.

Challenges of fashion companies with 3D technology are mainly connected to technical problems faced: 3D technology significantly facilitates the development of a product life cycle, but knowledge and skill of the user are still very important. Therefore, the distribution and introduction of virtual software systems in fashion companies of all levels (small, medium or large) is a problem faced mostly in the initial stage. Since, there are different profiles of users in companies e.g., pattern makers, designers & management are all involved in the product management and there is a lack of tool to fit different profiles of users. Technical challenges faced are for instance related to simulation problems, visual quality problems, ease of use, speed, acceptance and no availability of previous technical design details is also a challenge. While using 3D technology systems, achieving the required quality, aesthetical and hygienic characteristics of the finished products is also a challenge as the virtual tools available at the moment have limited features concerning with haptic interaction modalities of virtual cloths.

RQ3**:** How can third party organizations be helpful in making the fashion industry going forward towards 3D?

The role of the research institutions and textile associations which can be called as third party organizations in supporting the fashion companies for implementing 3D technology strategies is very essential. These organizations have a large expertise within 3D technology aspects applied to the fashion industry. Their pivotal role consist of being able to provide the need assistant to the companies that are in the initial start-up stage to launch implementation of 3D technology, and to the fashion companies as well that have already experience of working with 3D technology. Research institutions and textile associations can help with the challenges related to 3D virtual technology. The forms of support have been discovered include: conducting heavy research and providing publications on 3D virtual issues, producing new software's know how, providing different 3D educations, trainings and 3D seminars.

9.2 Recommendations for Further Improvements

There are number of areas within which further improvements can be made for making the fashion industry to implement 3D technology in every part of the industry. The following recommendations are made for the fashion companies, software providers and third party organizations.

Fashion Companies

The fashion companies are recommended to engage in partnerships with each other and other industries that will enable them to discover new ways and methods of designing and gaining the experience of using of new and relatively virtual tools. The knowledge sharing would also include of assisting another company that is determine to implement virtual technology in helping to provide guidelines and vital experience in how to start with virtual technologies.

Third Party Organizations

Organizations working to support fashion industry regarding 3D technology strategies, should enlarge their focus on fashion companies willing to experience virtual technology and also on the individual challenges of the companies who are already into virtualization in their business. This could be done through direct communication in personal meetings, network groups and follow up meeting once or twice a year. Third parties are recommended to promote even more 3D technology by educating and providing solutions to issues related to virtualizations. The ease of use must be in high priority for the adoption of 3D technology to happen and this can be only possible with the availability of continuous education of 3D. Therefore, the third parties must make the promotion of 3D technology as a high agenda, and it will be possible adequately to bring evolution of 3D completely in the fashion industry.

Few knowledge sharing platforms of 3D technology already exist to some extent in the fashion industry for instance conferences or key user meetings of software vendors are such platforms. Additionally, there are more and more fashion meetings already dedicated to the 3D topic. However, virtual software providers, textile associations and research institutions are recommended to take these initial attempts of knowledge sharing’s to the next step by establishing a knowledge platform, initially targeted at fashion companies of different levels. This would be a platform for sharing information and experience about 3D technology strategies and usage and which will build the companies knowledge and expertise in the area of virtualization. Knowledge sharing in the form of providing more education and seminars and particularly, fashion companies would have an essential role in this as they would also help each other on the concept of give and take by sharing experiences, stories and knowledge gatherings. This can be only possible with the openness of fashion companies, third parties and most importantly 3D technology providers by the integration with each other. This would help the fashion industry to revel and realize of new opportunities for 3D technology usage and would provide a platform on which the challenges faced by the fashion companies can be overcome by collective efforts.

This research can be used to provide practical insight to the fashion industry regarding virtual product designing and managing opportunities available, the fashion companies working with the virtual softwares, what are their selection criteria for 3D technologies, and their challenges. It can also be used to put forward recommendations on how to help the fashion companies who want to initiate the use of 3D technology. This research should however be recognized as an exploratory research and the results are not to be generalized.

9.3 Implications for Further Research

Based on the finding of current research, certain areas for further research are suggested:

- *How does 3D not look real enough*: Of course, the virtual tools are not perfect and it is also understandable that virtual is not reality. However, a research can be done that how the existing quality of the virtual tools can be improved and how the existing systems can be taken to the next step where there would be so many possibilities to resolve the issues of virtual appearance and haptic sensation of the virtual garments to make virtual as reality.

- *Research within a specific region:* This research was focused at only few case companies from global fashion industry. Furthermore, research could be expended to fashion industry within a specific region e.g., Asia, Europe, America etc. This could provide a wider exploratory research that how far has the 3D technology being implemented in fashion industry in specific part of the word. This would help software companies to understand the fashion industry of that specific part of the world and make them focus on the customer's needs.

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APPENDIX A: LIST OF INTERVIEWS

Company	Name	Position	Date
ADIDAS	Renate Eder	Team lead, Creation technologies	09.09.2013
DELTA GALIL	Esti Maoz	Corporate SVP	13.09.2013
ICICLE	Ye Shouzeng	General manager and Design director	18.09.2013
ARUSH	Isaac Gershevich	Director of production and planning	09.10.2013
Browzwear	Sharon Lim	Managing Director	10.10.2013
CAE Laboratory, Technical University of Dresden, Germany	Krzywinsk	Research Scientist	17.10.2013

APPENDIX B: SAMPLE CASE STUDY INTERVIEW QUESTIONS

GENERAL FACTORS OF 3D

1) How would you define 3D virtual technology?

2) What are your reasons for pursuing a 3D virtual pathway?

3) How did it all start (Usage of 3D virtual tools) and when for your own company?

4) How would you describe the trends & demand in the fashion market for 3D virtual tools and how many fashion companies do you thing are using 3D tools for product development and management around the globe?

INTERNAL FACTORS OF 3D

1. Which 3D tools for designing and managing products are being used by you and what is the selection criteria for these tools as there are many suppliers of these tools?

2. Are the CAD systems provided by various companies identical or not?

3. What are the main challenges which are faced by your company when using 3D tools for designing and managing the products, please highlight and also kindly state that how these can be overcome?

4. Is there any lack of a correlation between virtual model and garment pattern? Can the CAD software be improved?

EXTERNAL FACTORS OF 3D

1. In what way can third party organizations (i.e., software providers, textile associations etc) help you with your challenges related to 3D virtual technology?

2. Do the current 3D software tools fulfill the requirements for visual, haptic and other sensory properties when selecting textile and fashion?

3. What is the future of 3D technology? Are there any possibilities of creating “knowledge platform" between fashion companies for the 3D Software usage in the future?