Future Fashion Industry: The Effects of Virtualisation of the Product Development Process

By Logan McCage

PhD Thesis – 2024

Supervisors: Professor Caroline L. Davey & Professor Andrew B. Wootton

University of Salford

School of Arts, Media, and Creative Technology

Salford, United Kingdom

Table of Contents

List of Figures

Appendices

List of Tables

Appendices

Acknowledgements

This journey would not have been possible without the support and encouragement of many remarkable individuals. First and foremost, I express my sincere gratitude to my supervisors, Professor Caroline L. Davey and Professor Andrew B. Wootton. Your support, patience, and wisdom have guided me through this challenging process. Thank you. I also extend my gratitude to my examiners, Dr. Juan Hiriart and Dr. Hildie Heim, for being part of this journey and reviewing the early drafts of this thesis.

My heartfelt thanks goes to all my previous teachers, professors, and mentors who have shaped my academic journey. Thank you, Dr. Rick Cottle, for igniting my interest in virtual technologies and for the continuous support over the years. Special thanks to Dean Tim Isherwood for recognising my potential and encouraging me to pursue this path. Your support and constant supply of tissues during tough times have been greatly appreciated. Professor Allan Walker, your belief in me and the incredible opportunities you provided have been beyond anything I could have ever imagined. Thank you for having the confidence in me to embark on such a life-changing academic adventure.

To my mentors Ruth M., Joshua Y., Lena L., Jørgen S., Matthew A., and David M., thank you for your encouragement and guidance. You truly inspire me. Also, a heartfelt thank you to all my research participants. Your shared expertise and experiences have significantly contributed to this project, and I am deeply grateful for all that I have learnt from you. Special thanks to Mogens J., René M., Lise S., Rickard L., Aleasha K., and Kevin R. for welcoming me with such kindness and generosity into your organisations. I will always cherish that time together, and I look forward to future collaborations.

To my friends Maria P. and Alexander B., there are not enough words to express my gratitude. Your generosity, patience, and guidance have been crucial over the past few years, and I could not have completed this without your support. Also, to my friends Molly R., Molly J., Aylin W., and Mike G., thank you for keeping my spirits up and being there for me always. Your friendship has been a pillar of strength throughout this journey. I would also like to thank my students. You have taught me so much and have brought so much joy during these tough years. It has been a privilege to be part of your academic journeys.

To my grandfather Robert McCage, thank you for making it possible for me to pursue my studies all these years, and I wish you could be here to see me at the finish line. I miss you. To my supervisors, family, friends, and participants, I deeply appreciate the love, support, and encouragement that have carried me through. I dedicate this thesis to all who have made this possible.

To the fashion industry: we must do and be better. We have the opportunity to evolve and create a more responsible and effective fashion industry. Most importantly, we can create a positive impact for *all* across the value chain.

Declaration

I certify that the final thesis includes the approved corrections (if applicable) made to the original submission. I confirm that I have been granted the appropriate level of ethics approval for my research.

Signed:  Date: 7 August 2024

Abbreviations

AI	Artificial Intelligence
AMT	Advanced Manufacturing Technologies
AR	Augmented Reality
B2B	Business to Business
B2C	Business to Consumer
CAD	Computer-Aided Design
CGI	Computer-Generated Imagery
CNC	Cutting Numerical Control Machine
CPS	Cyber-Physical Systems
CSR	Corporate Social Responsibility
DAO	Decentralised Autonomous Organisations
DOI	Diffusion of Innovation Theory
DPC	Digital Product Creation
EDI	Electronic data interchange
ERP	Enterprise Resource Planning Systems
ESG	Environmental, Social, and Governance
GOTs	Global Organic Textiles Standard
ICT	Information Communication Technologies
IoT	Internet of Things
IT	Information Technologies
JIT	Just-In-Time
NFTs	Non-Fungible Tokens
PLM	Product Life Cycle Management Software
QR	Quick Response
RFID	Radio Frequency Identification Technology
SCT	Supply Chain Technologies
TAM	Technology Acceptance Model
UPC	Universal Product Code
VMI	Vendor-Management Inventory
VR	Virtual Reality

Abstract

Virtualisation in design, manufacturing, and sales is transforming the fashion industry. During the COVID-19 pandemic, traditional ways of garment presentation, such as fashion catwalk shows, shifted towards virtual showrooms, and digital samples became a main communication tool between brands and manufacturers. This doctoral research explores how virtualisation in the product development process is impacting the fashion and garment industry. To address this question, both quantitative and qualitative research were undertaken to: (i) understand the processes companies are using to implement virtualisation; (ii) examine the impact of virtualisation on the fashion industry's product development process, including its effects on issues such as 'craft' and 'authenticity'.

This PhD research significantly contributes to knowledge by offering new insights into virtualisation within the fashion industry. By combining theoretical humanities with applied science, the study provides a comprehensive academic analysis of how the industry adopts digital technology and virtualisation in the product development process. The doctoral research contributes to this emerging area of research by supporting improved understanding of technological transformation for the fashion and apparel / garment industry. Furthermore, it adds to the growing body of literature on technology, design, and production to future-proof the fashion industry.

Chapter 1: Introduction

1.0 Introduction to Chapter 1

This chapter introduces the PhD thesis, establishing the foundation for the research study and providing the rationale for its framework. The chapter begins with discussing the current state of the fashion industry and contemporary issues. Subsequent sections include:

- The impact of COVID-19
- Research question and objectives
- Research methodology
- Themes relevant to the thesis
- Contribution to knowledge
- Ethical approval
- Background to the PhD candidate

Together, these sections set the foundation for exploration of the PhD research question and objectives.

1.1 The state of the fashion industry

Throughout the value chain, the fashion industry is facing a number of challenges and issues regarding traditional industry practices. According to Press (2020), reevaluating long-standing industry processes to address concerns of overproduction and declining business growth is critical. Moreover, the COVID-19 pandemic intensified these issues, and revealed the instability of the fashion supply chain. Nevertheless, developing and implementing a responsible industry framework, while remaining profitable, is still subject for debate. In response, academics and industry professionals propose that digital technologies to enable virtualisation strategies will support the transformation of an outdated industry (as seen in Imed et al., 2022; Arribas and Alfaro, 2016).

Virtualisation is defined as simulating processes virtually to scale workloads and increase productivity. For example, 3D design software enables the prototyping and fitting stage of the product development process to be carried out virtually using digitised avatars. Thus, it is indicated that the number of physical garment samples and resources is significantly reduced as a result.

Despite the promising potential for digital technologies to transform the fashion industry, several challenges and barriers hinder their adoption and implementation. The fashion industry heavily relies on manual labour, making the virtualisation of sectors in the supply chain more challenging compared to technologically advanced industries with established foundations. Furthermore, the complex nature of the garment supply chain intensifies these challenges, resulting in a slow uptake and integration of digital technologies at scale. Addressing these challenges requires evaluating various technologies and processes to effectively support organisations across the value chain.

Within the current traditional fashion system many critical non-technology related issues exist – such as a lack of industry knowledge and technical design skills. Furthermore, terms such as digital transformation and fashion sustainability need established definitions and standards before virtual technologies can create true impact. The industry will need to undergo *'a double transformation'* to accommodate traditional business practises to gradually evolve and modernise (Coughlin et al., 2001; Lim, 2020).

1.2 The impact of COVID-19

During the COVID-19 pandemic, two instances where virtual fashion or 'digital fashion' emerged was in the context of the retail and back-end operations within product development. During the COVID-19 pandemic, traditional ways of garment presentation, such as fashion catwalk shows, shifted towards virtual showrooms, and digital samples became a main communication tool between brands and manufacturers.

In regard to the retail sector, sales, merchandising, and marketing teams were suddenly challenged to find new channels and strategies to engage customers and generate sales. Gaming apps and virtual try-ons became a common trend in consumer engagement strategies during lockdown. For example, luxury brands such as Burberry began to apply digital applications within promotion (Tsai, 2020). Interactive technologies and computer-generated imagery (CGI) are predicted to be the chosen method to reach younger generations, such as Generation Z – those born after the millennium (Vogue, 2020). As a result, discussions around opportunities for new mediums of technological communication emerged (as seen in Yotka, 2020); however, some experts such as Hall (2020) argue that effectiveness of digital solutions should be critically considered (as noted in Hall, 2020).

Moreover, non-essential brick-and-mortar stores were closed, prompting consumers to turn to ecommerce platforms. The shift to online shopping, revealed which brands had invested in strong digital ecommerce platforms and presences. According to Socha (2020) the shift towards online shopping habits is mostly likely to persist beyond the COVID-19 pandemic, underscoring the importance for brands to maintain a strong digital presence.[1]

In regard to back-end operations, the COVID-19 pandemic only intensified supply chain issues facing the fashion industry as well as revealed just how unstable the fashion supply chain is. Areas such as stock management, supply chains, and digital acceleration became key topics of webinars during lockdown (Fashion for Good et al., 2020). In addition, many brands began to reconsider the fashion calendar — the main schedule that administers fashion collections in the production, logistics, and depreciation of goods (Blanks, 2020).

Additionally, the COVID-19 pandemic acted as a catalyst for the industry to actively rethink its operational strategies. Many brands began investing and relying on virtual technologies and solutions to carry out business as normal. Brands were unable to create samples, conduct physical fittings, and plan for seasonal collections as a result of a global lockdown (Socha, 2020). However, 3D design software enabled brands and manufacturers to continue business operations. Brands that adopted 3D design technologies prior to the pandemic, such as Tommy Hilfiger (Turk, 2019), were predicted to most likely perform better post-pandemic in comparison to those

[1] The UK went into lockdown on 23 March 2020. By the end of March, many US states were in lockdown.

who did not. The pandemic accelerated the process of digitalisation in the fashion industry. Therefore, transforming a *"very human-based, artisanal"* means of production into a virtual process (Socha, 2020, p.7).

1.3 Research question and objectives

Virtualisation and digital technologies have the potential to create new ways of conducting business, support environmental efforts, and introduce new forms of visual mediums and communication. However, the fashion industry faces numerous challenges – including environmental crisis, outdated industry practices, and other external factors. Understanding the industry's current state and these challenges, is crucial in identifying areas where virtualisation will have an impact. Therefore, this doctoral research addresses the question:

> *How is virtualisation of the product development process impacting the fashion industry?*

To address the research question, the following objectives have been identified:

1. To understand the processes by which companies are undertaking virtualisation and the technologies enabling this.
2. To understand the impact of virtualisation of the product development process on the fashion industry.
    - including how virtualisation of design and product development processes has impacted issues relating to the fashion design profession, such as 'craft' and 'authenticity'.

1.4 Methodology – approach & rationale

This study adopts an interpretivist approach, utilising ethnography as the primary research method to answer the research question. According to Muratovski (2022, p.80), the main of objective of ethnography is, "...*to provide rich, holistic insight into various cultures and subcultures (people's views and actions), and the environments that surround them (sounds, sights, spaces, locations, etc)."*

An interpretivist approach allows the researcher to remain open to exploring the question within the industry, enabling key findings and understandings to 'emerge from the field' (Schwartz-Shea and Yanow, 2011; Atkinson and Hammersley, 2007). Hence, this study utilised an exploratory approach to observe in real-time the uptake of virtual technologies specifically in the product development process to answer the research question, aiming for objectivity without predetermined expectations. See *Chapter 4: Methodology* for a more in-depth discussion.

1.4.1 Research methods

The thesis adopts a mixed methods approach, utilising quantitative and qualitative, to address the various research objectives. The chosen methods includes:

- Survey
- Interviews
- Case studies (methods include interviews, focus groups and observation)

Each method will also be discussed in more depth in *Chapter 4: Methodology.*

1.4.2 Potential risks and mitigation strategy

- Risk 1 – Research participants unwilling to participate in research
- Risk 2 – Companies unwilling to be a focus for case study research (and COVID-19 restrictions lifted)

Potential mitigation strategy – If problems are encountered gathering data, a survey of fashion design students might be conducted to explore attitudes of the new generation of designers to 3D design software.

1.5 Themes relevant to the thesis

From the academic and industry literature, emerging themes such as Industry 4.0 and craft and authenticity were prevalent in regard to digital transformation, virtualisation, and technology adoption within the fashion industry. These themes provided context and understanding to develop the research methodology.

1.5.1 The Fourth Industrial Revolution – Industry 4.0

The fashion and garment industry has been greatly shaped by industrialisation– starting with the First Industrial Revolution. The Fourth Industrial Revolution, also called Industry 4.0, is a growing topic amongst academics, and is predicted to transform all manufacturing industries, including the fashion and garment industry. According to Bertola and Teunissen (2018, p.353), Industry 4.0 is described as:

> *A model where new modes of production and consumption will dramatically transform all major industrial systems; it has been targeted by many governmental plans as a goal for a sustainable future.*

In the context of the fashion industry, this PhD study considers the wider literature on the paradigm shift of Industry 4.0 as the defining technologies and principles of the paradigm are relevant to this study, as they enable virtualisation. Key technologies defining Industry 4.0, such as Radio Frequency Identification (RFID) and blockchain, are projected to have the potential to support transparency and traceability throughout a fashion garment’s life cycle. Additionally, 3D design technologies allow fashion and technical designers to create virtual garment prototypes – replacing the need for initial physical samples.

Moreover, integrating virtual technologies associated with Industry 4.0 is expected to support environmental efforts and promote a 'circular economy'. Industry 4.0 aligns with a circular design approach and economy, which aims to create a system of *“designing out waste and pollution, keeping products and materials in use, and regenerating natural systems”* (Ellen MacArthur Foundation, 2017). Environmental and socially responsible efforts were important prior to the COVID-19 pandemic; however, they became highly pressing post-COVID-19 as consumers became aware (Davey, 2020).

1.5.2 Craft & authenticity

The fashion and apparel / garment industry has a history of technological resistance. The paradox between craft and industrialisation is evident, as resistance towards 3D design software can be seen among some stakeholders. The rationale is that technology takes away from the ‘craft’ or ‘authenticity’ of the product or results in replacing the crafter altogether. For example, some experts suggest that the luxury and haute couture sector will most likely resist accepting digital solutions, as processes are highly tactile, visual, and emotional to achieve the highest craft quality (Archille, 2018; Socha, 2020). Experts predicted the uptake of technology would be more challenging for heritage brands to accept; however, Socha (2020), argues there are value-adding opportunities such as process efficiency and precision in craft. This theme is considered, as stakeholders are an important variable within the equation of the success or failure of technology adoption and diffusion – attitude and mindset can become barriers or enablers. Thus, themes of craft and authenticity are reviewed and considered in this PhD thesis.

1.6 Contribution to knowledge

There are currently few academic studies that explore in depth this subject in relation to the fashion industry, and very few on industry changes since the COVID-19 pandemic. The following are available (for further details, see Appendix A):

- Arribas and Alfaro (2016) – Conference Paper
- Arribas and Alfaro (2018) – Case Study
- Bertola and Teunissen (2018) – Journal Article
- Iqbal (2012)– Master's Thesis
- Kaiser et al. (2014) – Case Study
- Kaplandidou (2018) – Master's Thesis
- Paparhistou (2016)– PhD Thesis
- Papahristou and Bilalis (2017) – Qualitative Study
- Papahristou et al. (2017) – Conference Paper
- Santos et al. (2020) – Paper as part of a PhD study

1.7 Ethical approval

The application for ethical approval was approved on 5 February 2021. A copy of the application is provided in Appendix J.

1.8 Background to the PhD student

From her studies and experiences, the author has developed a true passion for 3D digital design, but also to do her part as a fashion practitioner and academic to contribute to the transformation of the fashion industry. Through this PhD, she hopes to contribute to this growing area of research and support improved understanding of this transformation for the fashion and garment industry. For further details see "About the Author" in Appendix K.

Chapter 2: Literature Review: Technology adoption in the fashion industry

2.0 Introduction to Chapter 2

The literature exploration began with an investigation into which technologies are – or *not* – utilised within the fashion industry. When the PhD study commenced during the COVID-19 lockdown in the United Kingdom, there was initially a lack of relevant academic literature. Existing literature is well-developed in specific fields such as computer science, focusing on the technical development of specialised software and technologies such as 3D body scanning and 3D printing (additive manufacturing). Additionally, there is extensive literature in fields such as business management discussing manufacturing strategies and business models.

The pandemic accelerated the adoption of virtual enabling technologies – such as 3D design software, within the product development process. Consequently, industry literature provided insights into current developments, leading to themes for further academic exploration, such as information technologies (IT), 3D design software, and digital fashion. Furthermore, it identified paradigm shifts – such as The Fourth Industrial Revolution, circular economy, and reshoring / nearshoring.

The literature review provides a sound analysis and coherent interpretation of the available academic and industry literature, forming a foundation for the methodology and understanding of the topic. The four primary topics within the literature explored in this chapter are outlined as follows (see Figure 2.1):

- Virtualisation – Key technologies within the fashion industry
- Slow uptake of virtual technologies within garment product development
- A history of innovation
- Industry 4.0 paradigm for the fashion industry

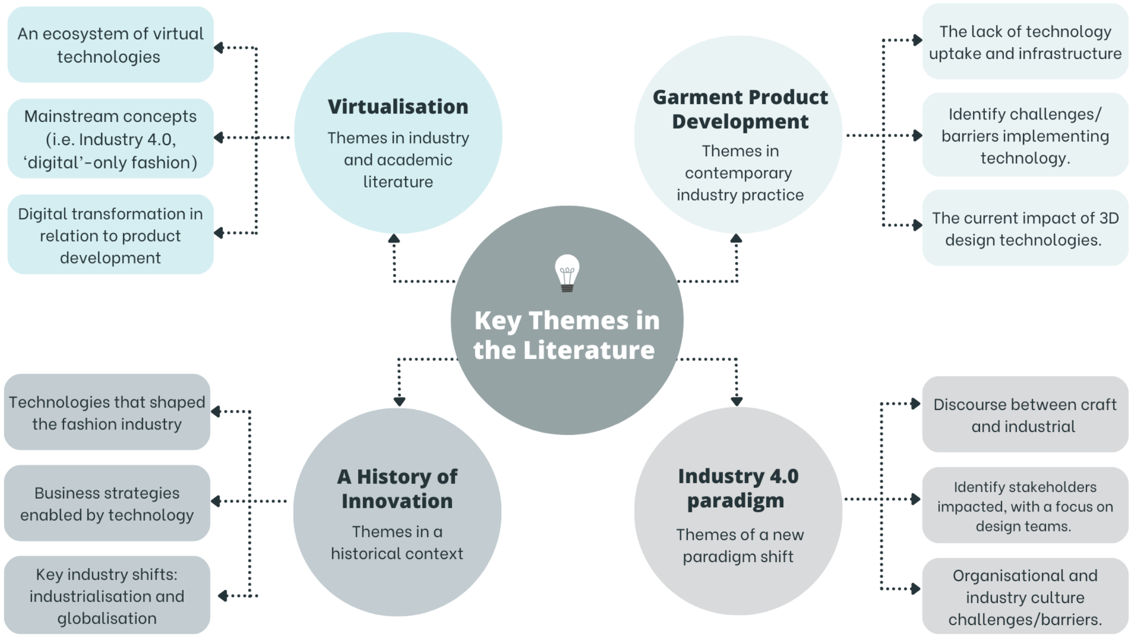


Figure 2.1 Key Themes in the Literature

This chapter begins with a general overview of the global fashion industry's significance to highlight the complexity of the garment supply chain and the inner workings of the industry. The main focus of this study is the garment product development process, which falls within the apparel/garment manufacturer sector as shown in Figure 2.2. This figure outlines activities carried out throughout the product life cycle and will be used to help understand the impact of virtualisation across the supply chain. The author has adapted the diagram to include the consumer within the value chain.

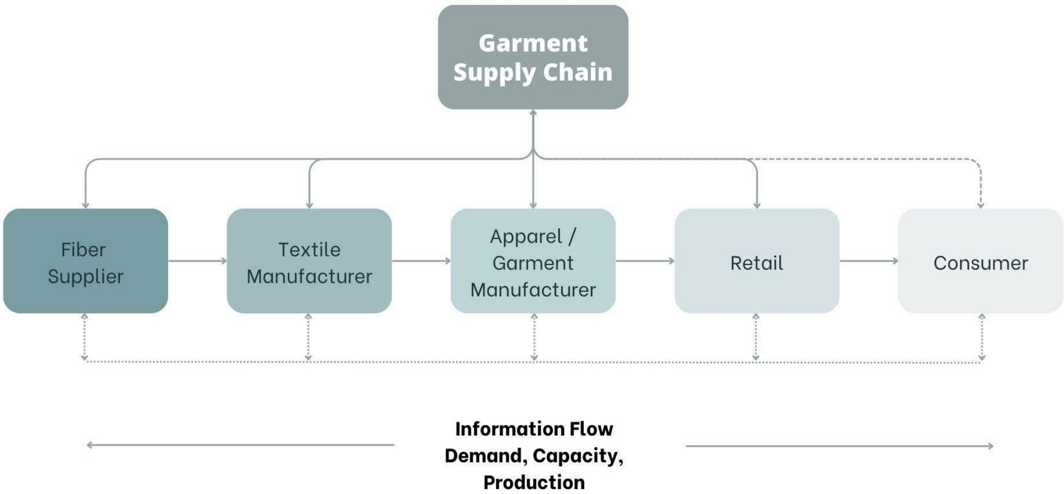


Figure 2.2. The Textile and Fashion Industry: Areas of Activity. Adapted from Coughlin et al. (2001), p.81.

In addition, there are a number of terms used when discussing the fashion industry, and these are briefly defined in the box below.

Key terms

The following terms are relevant to chapter 2 and are briefly defined here.

Fashion Industry – A global industry involving the production and selling of fashion commodities and services. The fashion industry includes sectors in: design, manufacturing, distribution, marketing, retailing, advertising, and promotion (Dillon, 2012).

Garment Industry –The term used to define the sector of the fashion industry where garments are designed, manufactured, and sold.

Fashion Textile Industry – The term used to define the sector of the fashion industry where textiles are created to produce garments.

Fibre Supplier – The supplier for the procurement of fibres for the creation of textiles.

Fashion Retail – The selling of fashion goods and services to customers for personal use.

Product Line – A mixture of selected fashion products offered by a retailer for sale.

Fast Fashion – A business strategy which uses quick manufacturing techniques to provide low-cost clothing to meet the peak of consumer demands.

2.1 A general overview of the global fashion industry

Since the earliest forms of civilization, the textile and garment industries have played a key role in the economy and are highly regarded as power sources of early industrialisation (Coughlin et al., 2001). These two sectors were the first to globalise manufacturing and have experienced the most extensive global expansion among industries (Hines, 2004). The apparel industry significantly contributes to economic development, with garment production serving as a key driver for national development in low-income countries (Fernandez-Stark et al., 2011). Regarding apparel retail, the sector adds value by creating jobs. Wholesale and retail create roughly 75% of the value within the supply chain (Coughlin et al., 2001).

2.1.1 Fashion market segmentation

The fashion industry organises goods into tiers of product differentiation to meet the needs of a diverse range of target markets (See Figure 2.3). According to Taplin (2014), patterns of consumption began to evolve in the 1960s due to socio-economic factors such as higher disposable income, urbanisation, and the development of the shopping mall. These factors played a pivotal role as consumers began to develop individual expression and identity. Additionally, women entering the workforce and promotional activities targeting young adults drove fashion consumption. Marketers responded by developing target markets, demographics, and product segmentation for fashion goods, varying in price, quality, and trend (Taplin, 2014). See Figure 2.3.

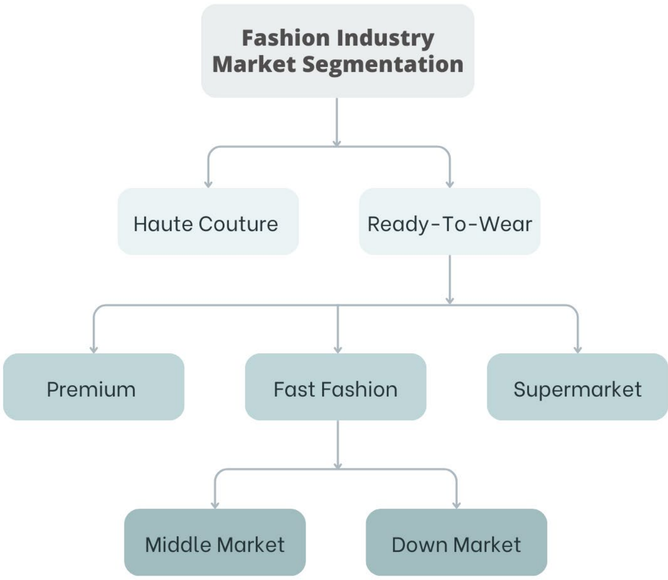


Figure 2.3 Fashion market segmentation
From Rathinamoorthy (2019, p.3).

Around the late 1980s, Taplin (2014) explains that the fashion industry relied heavily on fashion forecasting to predict trends and develop collections – a practice still widely used today. The science of observing buying patterns and habits became crucial for forecasting demand – also known as ‘situation awareness’.

In the 1990's, consumer demand shifted towards basic garments, prompting mass production of standard products at low costs. To remain competitive, retailers in the early 1990s began drawing inspiration from fashion runways to design ‘trendy’ pieces. Consequently, more collections were added to the fashion calendar, forcing brands to increase production (Taplin,2014). The increase in the demand led to a culture of frequent sales and markdowns as organisations struggled to predict the consumer preferences, resulting in overproduction (Bhardwaj and Fairhurst, 2010). Understanding fashion market segmentation is important to this study as the acceptance or rejection of virtual technologies correlates with the level of differentiation (See Section 2.2.2 Fashion business strategies enabled by technology).

2.1.2 The Garment Product Development Process

This study focuses specifically on garment product development. Understanding the process is essential for identifying digital technologies and assessing impact of virtualisation throughout the value chain. Product development is *the "design and engineering of products that are serviceable for the target consumer, marketable, manufacturable, and profitable"* (Senanayake, p.21, 2015). It is important to note that there are diverse business models in fashion design, product development, and production, with each organisation utilising their own processes.

As seen in Figure 2.2, the garment supply chain depends on a variety of different sectors made up of their own ecosystem of processes. These sectors differ in terms of capital investment, lead times for production facility set ups, and resource needs (Dillon, 2018; Coughlin, et al. 2001). Strategic planning is crucial for the seamless operation of each sector within the garment supply chain.

The production of fashion goods is laborious. Garment assembly, development, and the procurement of materials required is often carried out and sourced from multiple countries (Nayak and Padhye, 2015). The markets within the textile and garment sectors vary widely in product volume and variety, ranging from little innovation to extensive of design and development. Some markets may demand as many as 15,000 units of a single design and colour (Coughlin et al., 2001).

Traditionally, these processes were centralised, with garments made inhouse. However, fashion brands following just-in-time principles and the fast fashion model, have significantly reduced lead times by months (Senanayake, 2015). As a result of the increase in the number of collections and style ranges offered by brands, supply chain efficiency and agility become more important. Even a minor delay can greatly disrupt the entire planning process. Furthermore, timing becomes critical as fast fashion trends rapidly change to meet consumer demands (Senanayake, 2015).

According to Nayak and Padhye (2015), the challenges in garment manufacturing include as follows:

- Sourcing cheap labour because of short life cycles
- High volatility
- Low predictability
- High level of impulse purchases
- Quick market response

One primary objective is to minimise production cost by prioritising inexpensive raw materials and delivery, although labour costs are on the rise (Nayak and Padhye, 2015). Table 2.1 provides a general overview of the garment product development process, adapted from Senanayake (2015, p.22-26).

Stage	Function
Stage 1. Planning and Research	Stage 1. Planning and Research: the product range is planned to build seasonal collections. Stakeholders from cross-functional teams (e.g. merchandisers, designers, etc.) are involved (Fernandez-Stark et.al., 2011). Main activities carried out include trend forecasting, data analysis from previous sales, research and development, and market research (e.g. target market, design details, sales goals, etc.)
Stage 2. Design	During Stage 2. Design: the design team develops collections and concepts based on the range plan set in Stage 1 as well as successful designs from previous seasons. Design teams work alongside data analysts to stay up to date on target market trends through observing consumer behaviour and social media activity. Textile and graphic designers are also consulted. Design details such as colour, trims, fabrics, etc, are decided.
Stage 3. Design Development	Stage 3. Design Development: sampling and prototyping occur to plan: costs, fit, silhouettes, feasibility of design, colour testing, patternmaking, raw materials. Technical garment packages or specifications are created by technical designers developed for each style. Development or sourcing of raw materials and textiles are carried out at this stage.

Stage 4. Line Presentation and Marketing	Stage 4. Line Presentation and Marketing: the range plan of styles is presented to executive decision makers to accept or reject styles.
Stage 5. Production	Stage 5. Production: the sourcing decisions such as contractors and production facilities are negotiated to find the best cost, quality, delivery, etc. Final prototypes are created and final decisions on size ranges, order quantity, and costs are made. Then finalised samples are put into production.

Table 2.1 Product Development Process
Adapted from Senanayake, M. (2015), p. 22-26.

2.2 Virtualisation – Key technologies within the fashion industry

The literature on technology adoption and the segmentation of technology uptake within the fashion industry is fragmented and undevelopment (Hoque et al., 2020). This presents a challenge when attempting to identify key areas of literature of technologies enabling virtualisation. However, relevant studies can be found in fields such as computer science and engineering, business and retail, and supply chain management. In regard to the literature surrounding ‘digital fashion’, Nobile et al. (2021) highlight a predominant focus on communication and marketing, with less emphasis on design and production. Technology adoption regarding the fashion supply chain has been a significant topic of interest among researchers since the late 1990s (Hoque et al., 2020).

To understand the impact and feasibility of new digital technologies and paradigms promising solutions to transform the fashion industry, the general literature surrounding technology adoption and the digital technologies enabling virtualisation is examined. Connectivity is a key theme in the success of future virtual frameworks such as end-to-end digital transformation to support smart factories. This section provides an overview of key technologies that have influenced the fashion industry and examines the existing technological infrastructure.

2.2.1 Information Communication Technologies (ICT)

The general literature extensively covers Information Communication Technologies (ICT) and Supply Chain Technologies (SCT). ICT is the accepted term to encompass a broad range of communication and Information Technologies (IT) – including the internet, software, mobile phones, and social networking (AIMS, 2020). These technologies are explored in the academic literature focused on the fashion retail sector, as well as management and manufacturing journals.

Because of the complexity of garment manufacturing, the adoption of ICT has been crucial, not only in the apparel industry but across 90% of all manufacturing industries (Duarte et al., 2018). In the academic literature on fashion technology, key technologies such as SCT, ICT, 2D / 3D CAD, have led to positive outcomes for both long-term and short-term performance (Lee et al., 2014; Easters, 2012). For example, the benefits of ICT include (Hines, 2004, p.25):

- Increases efficiency in time and costs.
- Reduces marginal errors when sharing data.
- Enables the strategies for the implementation of waste prevention.
- Provides value-adding opportunities for consumers.
- Enhances transparency through information and goods traceability.

An essential ICT technology for ensuring business efficiency is Enterprise Resource Planning (ERP) systems, which *"coordinate orders, capacity, and material supplies"* (Coughlin et al., 2001, p.82). Shared information among industry partners includes timing, sales projections from previous periods, and data concerning production stage capacities.

Additionally, logistics-related technologies are extensively discussed within the literature. According to Coughlin et al. (2001), these technologies have significantly accelerated order-cycle times from weeks to hours. The following technologies, highlighted in the literature (Smith and Weil, 2005; Coughlin et al., 2001; Nayak and Padhye, 2015), have reshaped processing:

- **Electronic data interchange (EDI)** – developed in the 1970s, EDI is defined as the ability to exchange data – such as information on orders or shipments– between suppliers and customers. A key benefit of EDI is that it is lower cost in set up and use, compared to traditional EDI.

- **Vendor- management inventory (VMI)** – a system for the replenishment of orders based on forecasted consumption of consumers' past sales to reduce inventory – thereby reducing future markdowns.
- **Scanner and Barcode System** – introduced in the 1980s, is described as *transformative* and *revolutionary* for the fashion and product industries. The technology allows: automated restocking of purchased items, automated shipping to increase efficiency, and real time data on the success (or lack of success) of a product.

A barcode is an *"optical machine-readable representation of data relating to the object to which it is attached"* (Wong, 2014, p.2). Initially developed in 1949, barcoding became commercially viable for retail use in 1974 with the introduction of the Universal Product Code (UPC), first appearing on chewing packets (Wong, 2014). However, barcoding has limitations, such as its inability to alter data once the label is printed and its operation range constraints. In response, Radio frequency identification (RFID) technology as an alternative (Hines, 2004). RFID is defined as (Wong, 2014, p.3),

> *A generic term used to describe technologies that involve the use of a wireless non-contact system. This utilises radio waves to transfer data from an RFID tag attached to an object, for the purposes of automatic identification and tracking.*

RFID is a large area of research and is applicable across industries (as seen in Attaran, 2012) – including the fashion industry (i.e. Wong, 2014; Bottani et al., 2014; Choi et al., 2018). While the roots of radio frequency engineering trace back to 1864, RFID's application in the retail sector began to gain momentum in the early 2000s (Al-Kassab et al., 2010).

Studies have highlighted the positive benefits of RFID technology for the fashion supply chain, including increased profitability (Choi et al., 2015) and enhanced supply chain performance (Ali and Haseeb, 2019). RFID's versatility extends from retail applications, where it leverages customer data to drive sales (Hines, 2004), to production environments, where it improves logistics and supply chain efficiency (Bottani et al, 2014). Furthermore, RFID has gained much attention for enhancing transparency and traceability to support environmental initiatives within the industry (e.g. Keung Kwok and Wu, 2009; Denuwara et al., 2019; Voipio et al., 2021).

Within the literature discussed in this section, various authors highlight concepts crucial for the widespread adoption of technologies and processes. For example, Hines (2004) discusses the topic of open platform technologies in facilitating the success and development of ICTs in the global marketplace. Open-source platforms, in contrast to legacy systems, establish standardised systems for documents exchange (Hines, 2004). Additionally, IT systems that can withstand handling vast amounts of data, underscore the importance of strategic alliances and collaborative relationships (Coughlin et al., 2001).

2.2.2 Fashion business strategies enabled by technology

As previously discussed, Information Communication Technology (ICT) has significantly transformed the fashion industry by enabling supply chain agility and efficiency (Bruce and Daly, 2016). This technological advancement has also facilitated business strategies such as Quick Response (QR) and Just-In-Time (JIT), providing companies with a *“competitive edge in the market”* (Bhardwaj and Fairhurts, 2010, p.171). These strategies are extensively studied in the fields of business management literature and play crucial roles in the intersection of fashion and industry practices and technology.

Just-In-Time Manufacturing in Fashion Industry

Just-in-time manufacturing (JIT) – also referred to as lean manufacturing (as seen in Nayak and Padhye, 2015) – originated from the automotive industry between 1948 and 1975. Toyota’s *‘Toyota Production System’* aimed to establish a more agile manufacturing system, reducing lead times, minimising cost, and maximising quality by eliminating unnecessary inventory, utilising the inventory-management system Kanban. This system triggers restocking signals when inventory of a specific material is low, ensuring timely replenishment with exact quantities required. Moreover, a key element of JIT strategy involves local production to swifty respond to market demand (Sherman, 2018).

In contrast to the automotive industry, the fashion industry operates on a different supply chain model. Known as a 'push' method, it is demand driven and relies heavily on fashion forecasting to anticipate consumer preferences well in advance of production (Sherman, 2018). Products are designed and manufactured months ahead of their intended season, often leading to reliance on sales through discounting strategies. Coughlin et al. (2001) characterise this approach as an 'inverted pyramid'. Meaning that unlike other industries, where a limited range of raw materials is transformed into a wide array of end products that cannot be easily reversed once produced. Consequently, unsold stock accumulates when products fail to meet consumer expectations. JIT manufacturing principles mitigate these risks by maintaining materials in a minimally differentiated state until close to production, allowing decisions on colour and silhouette to align more closely with actual demand (Coughlin et al., 2001).

Fast Fashion Phenomenon

In the early 1990s, the adoption of just-in-time (JIT) manufacturing principles revolutionised the fashion supply chain (Crofton and Dopico, 2007). Entrepreneur Amancio Ortega Gaona, through his fashion company Zara – a part of Inditex – pioneered JIT principles in garment manufacturing. According to Nayak and Padhye (2015), approximately 292 tasks are involved in each seasonal product's development cycle. Major manufacturers typically produce between 2,000 and 4,000 products annually. In contrast, Zara manages roughly 10,000 products simultaneously by leveraging JIT principles (Petro, 2012).

Several factors contribute to Zara's efficiency. Firstly, its suppliers are close to their distribution centres in Spain, Morocco, and Portugal, facilitating a highly efficient vertical integration system (Taplin, 2014). In addition, Zara operates automated factories that cut and dye fabrics based on real-time demand rather than relying on outsourced labour (Sherman, 2018). Trending materials are swiftly procured, and design teams begin designing based on selected materials, finalising designs closer to the production timeline. With these capabilities, Zara introduces new products globally twice a week, achieving a rapid turnaround time of 10 to 15 days from design to shop floor (Petro, 2012). The retailer ensures new products are consistently available on demand (Bruce and Daly, 2016).

Zara's ability to quickly respond to fashion trends compelled other retailers to adopt similar strategies to maintain competitiveness. While Zara is credited with popularising the fast fashion model, Italian brand Benetton initially pioneered it; however, Benetton struggled to offer trendy pieces at competitive prices. Swedish retailer H&M successfully emulated Zara's business model by providing quality, on-trend products at an affordable price, thereby effectively competing in the fast fashion market (Taplin, 2014).

The term '*fast fashion'* was coined in the *New York Times* in 1989 in response to Zara's business model (O'Neil, 2020). Fast fashion is defined as "*a business strategy which aims to reduce the processes involved in the buying cycle and lead times for getting new fashion products into stores, in order to satisfy consumer demand at its peak"* **(**Parker-Strak and Barnes, 2020, p. 519). Over time, the term has developed a negative connotation, often described as "*low-cost clothing collections that mimic current luxury fashion trends"* (Wang, et al., 2020 p.4). It is also referred to as '*throwaway fashion'* and *'quick fashion'* (Bhardwaj & Fairhurst, 2010).

Fast fashion has revolutionised traditional manufacturing process through implementation of communication technology and real time information exchange (Bertola and Teunissen, 2018). Todeschini (2020) suggests that fast fashion retailers are most likely to create the most innovation and invest in new technologies to enhance productivity, offer affordable products, and shorten delivery and product creation lead times. As a result, the uptake of new technologies and strategies across various sectors has significantly impacted fashion business (Coughlin et al., 2001). The fast fashion business model has intensified competition, requiring strategic marketing, and substantial capital investment (Bhardwaj and Fairhurst, 2010).

Quick Response (QR)

Traditionally manufacturers determined what to produce, and retailers convinced consumers to purchase those products. However, what is produced today is based on what consumers demand. For this to work, strategic alliances between retailers and suppliers are required to streamline processes, reduce costs, mitigate risks, and minimise delays in delivery fashion goods (Coughlin et al., 2001). Research from the

1980s and 1990s demonstrated that collaborative efforts and information sharing across stakeholders in the product lifecycle significantly reduced lead times, boosted profits, and expanded garment choices for consumers (Hines, 2004). Described as a *“set of independent companies that work closely together to manage the flow of goods and services along the entire value chain”,* value-adding partnerships between retailers and suppliers have become pivotal (Johnston and Lawrence, 1988, p.1; Easters, 2012, p.46). Effective communication and nurturing personal relationships among stakeholders are essential to align design, sales, marketing, and financial efforts towards creating desirable products and driving profitability (Fernandez-Stark, et al., 2011).

According to Coughlin et al. (2001), strategic alliances or value-adding partnerships led to the Quick Response strategy – originally developed by Kurt Salmon Associates (KSA) in the 1980s (Hines, 2004). This approach has influenced current industry practices, including:

- Establishment and maintenance of solid strategic alliances throughout the garment lifecycle to ensure efficiency, quality products, and prompt delivery to the shop floor.
- Shifting control to consumers who dictate production instead of retailers pushing goods onto the market.
- Reduction of inventory through accelerated movement of goods and information across the supply chain.

Bertola and Teunissen (2018) argue that innovations in the fashion industry are mainly focused on enhancing retailer-consumer relationships. Technological advancements, coupled with the QR strategy has transformed fashion manufacturing, branding, retail, and merchandising into consumer-centric approaches aimed at maintaining competitiveness and profitability. In essence, retailers and merchandisers control the trade (Nayake and Padhye, 2015).

2.2.3 3D design technologies – themes in the literature

3D digital technologies are key technologies and areas of literature to examine for this study. The area of 3D design technologies is an interdisciplinary field and described as *‘transformative’* and *‘disruptive’* (Court, 2015; Arribas and Alfaro, 2018).

Established areas of research on the topic of virtualisation and 3D design technologies within the literature include 3D printing, 3D body scanning, 3D prototyping, and marketing; however, this literature is also scarce within their respective fields and requires further research. 3D design technologies are predicted to offer benefits such as an increased creativity, mass customisation, and smaller batches of production in a variety of areas along the value chain (Arribas and Alfaro, 2018). See Figure 2.4. The affordability of some 3D design technologies such as 3D printers has allowed for industry application (Nayak and Padhye, 2015). Figure 2.3 in Arribas and Alfaro (2018) demonstrates the benefits of 3D digital technologies based on case study research along the value chain.

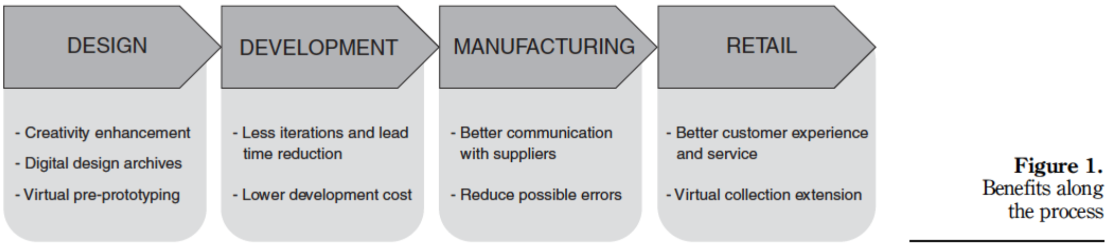


Figure 2.4 Benefits of Digital Technologies Along the Value Chain
Cited from Arribas and Alfaro (2018, p.247).

For this study, the literature focusing on 3D design software is highly relevant to understand how virtualisation will impact the garment product development process. Three main areas within the literature on 3D design software are as follows:

Design and modelling – benefits of 3D design software

The literature regarding 3D design software and 3D digital prototyping is scarce and lacks depth by focusing on the *'visualisation'* or the *'realness'* of digital fabric application for 3D digital prototyping (i.e. Buyukasian et al., 2018; Kim et al., 2020; Nechno, et al., 2021). In addition, there are many studies on the benefits of the technology during the design and development of garments– such as improved precision and functionality of a design, cost savings, improved communication (Teyeme et al., 2021; Maksimovic, 2020; Choi, 2015; Wang et al., 2002; Zangue et al., 2020). Papahristou & Bilalis (2017, pp.1) state that carrying out garment digital prototyping allows for *"...formalising and defining in a deterministic way the result of their activities*." During the design and development stage, the process of creating prototypes, carrying out fittings, and altering garments is a tedious, repetitive, and costly cycle (Arribas and Alfaro, 2018). Some companies make more than five samples per style. 3D design software is believed to improve the prototyping and fit stage (Nayak and Padhye, 2015). However, these studies lack empirical research, or lack critical analysis as the study is tailored to a specific scenario that does not reflect the general industry. For example:

Education and pedagogical framework

Education is also an important discussion regarding the impact of 3D design tools for upskilling industry professionals and for designing new pedagogical approaches for students (Papachristou and Billalis, 2016; Park et.al, 2011; Senanayake, 2015; Alfaro and Arribas, 2018). In addition, studies as seen in Zang et al. (2018) developed a practical framework of intuitive methods for integrating 3D design tools for accurate pattern development within a workflow – 3D → 2D → 3D mechanism.

Manufacturing, retail, and management strategies

In addition, 3D design software is discussed in literature focusing on digital transformation related to the fields of manufacturing, retail, and management. For example, the literature regarding the potential opportunities for 3D digital tools to be utilised within fashion retail and customer experience – such as virtual try-ons or sensory enabling technologies can be seen in the studies by Istook et al., 2011; Volino et al., 2004; Kim and Forsythe, 2009. In Alfaro and Arribas (2018), the study focuses on how innovation and digital transformation will affect the fashion industry. The empirical research followed and observed a couture designer utilising 3D design technology, including 3D printing and 3D design software, to create a pair of trainers. By improving the product development 3D design software might enable the strategy of design, sell, make instead of the traditional method of design, make sell (Ley, 2020). However, the study focuses on the development of footwear – not apparel.

Mathematics, computer science, and engineering of 3D design software

Another significant area of research regarding 3D design technology can be found in the field of mechanical engineering and computer science, focusing on developing mathematical equations for the simulation of fabrics and hardware (Hinds and

McCartney, 1990). According to Volino et al. (2004), mechanical engineering of virtual cloth has led to the advancement of software and usability in the garment industry. In addition, the researchers identify two types of 3D modelling software:

- 3D rendering software unintended for designing fashion garments, such as MayaCloth and 3DStudio.
- Original simulation 3D CAD design software (e.g. Browzwear's V-Stitcher and Optitex)– specifically for garment product development.

The virtualisation of garment making systems began in the 1990s (as seen in Hinds and McCartney, 1990) with the practical application of garment simulation (See Figure 2.2). However, the initial application of cloth simulation began in the late eighties and developed in computer graphics (Volino et.al, 2004). Traditionally, 3D CAD programmes in the fashion industry were designed with pattern makers or technical designers in mind (Choi and Ko, 2005), while fashion designers preferred 2D flat sketches to communicate ideas (Wang et al., 2002).

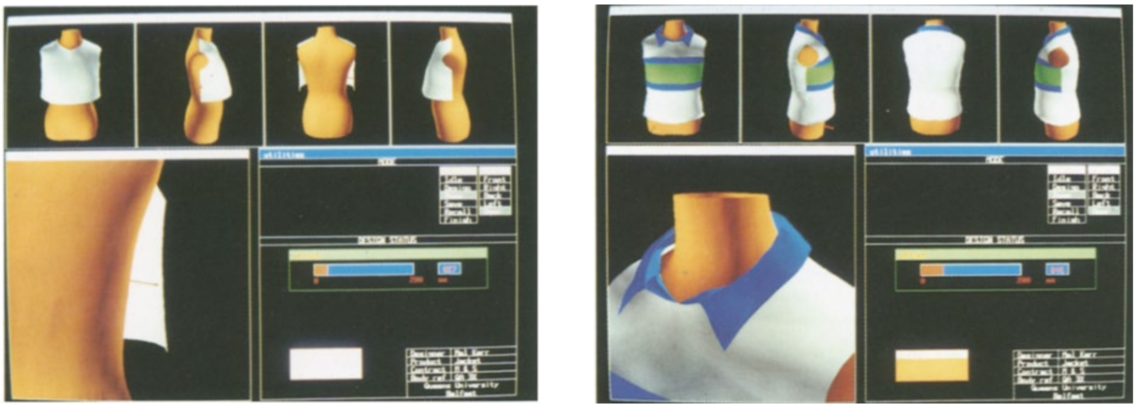


Figure 2.2 Early Virtualisation: 3D Garment Development
From Hinds and McCartney (1990, p.4)

The uptake of 3D CAD software has played a major role in the transformation of many design and product development industries– such as the automotive industry and architecture (Papahristou and Bilalis, 2017). However, uptake of 3D design software within the fashion industry has been relatively low until 2020 as a result of the COVID-19 pandemic. As discussed previously, the development of 3D design and prototyping software began in the early 1990s. In 2007, 3D virtual solutions company Browzwear reported 150 companies utilising their software (Easters, 2012). Within the literature, the lack of uptake was mainly due to underdeveloped hardware and software as well as the complexity of fabric simulation (Papahristou & Bilalis, 2017; Fang and Ding, 2008). An earlier study by Volino et al. (2004) considered 3D design software a *'bottleneck'* as it lacks 'interactivity'– the process of design and simulation to work simultaneously – which slows down the designing process. Offering real-time alterations to a garment and accurate avatars would create a more fluid process.

The COVID-19 pandemic, however, has accelerated digital transformation and the uptake of 3D design software in the fashion industry (Nobile et al., 2021; Kalypso, 2020). As mentioned previously, garment development and production remain traditional relying on manual processes, and the uptake of 3D design software was low prior to the COVID-19 pandemic. The advances in 3D design software and hardware, such as CLO Virtual Solutions and Browzwear, are growing in popularity.

2.3 Slow uptake of virtual technologies within garment product development

Despite the introduction of various digital technologies to the fashion industry over recent decades, their adoption within design and product development has been comparatively slow when compared to other sectors. For example, traditional computer-aided design (CAD) was first introduced in the 1970's (Zhang et al., 2008). However, a survey by Abernathy et al. (1991) revealed that only 40% of U.S. apparel companies utilised 2D CAD software for product creation by 1992. While the industry has made strides in adopting e-commerce and technology for marketing purposes, uptake of advanced technologies like artificial intelligence and advanced product development tools has lagged (Doeringer and Crean, 2005; Socha, 2020).

Key barriers for new technology adoption and implementation discussed within the literature include high initial investment costs and a skills gap– defined as a lack of necessary skills due to slow evolution within the industry (Duarte et al., 2018). Decision makers must carefully consider startup costs, ongoing maintenance expenses, and the need for training when evaluating technology investments.

2.3.1 Technology adoption curve

The general literature on technology adoption is particularly relevant to this study, emphasising factors such as organisational culture, upper management and leadership, and an organisation's level of innovation. These elements significantly influence whether technology initiatives succeed or fail, and whether they are accepted or rejected (Ko et al., 2007). For instance, McDermott and Stock (1999) noted that the implementation of advanced manufacturing technologies (AMT), can be hindered by a lack of knowledge and willingness among upper management to embrace these technologies. Therefore, organisational culture plays a pivotal role in supporting technology adoption to achieve optimal effectiveness.

A review of the literature highlights several key theories addressing technology adoption and diffusion. Specifically, Everett Rogers' Diffusion of Innovation (DOI) and Fred D. Daves' Technology Acceptance Model (TAM) are widely referenced in both general literature and studies focused on technology adoption in the fashion industry (as seen in Hoque et al.,2020; Kim and Forsythe, 2008; Yan and Fiorito, 2007). These theories predict adoption behaviours on user perceptions, such as user-friendliness and willingness to utilise new technology (e.g. Kim and Forsythe, 2009).

In addition, Everett Roger's Diffusion of Innovation Theory, provides a useful framework for evaluating, adopting, and implementing technology. The theory considers the adoption of innovations, such as new ideas or objects by a population over a period of time (Yan and Fiorito, 2007). Rogers' 1995 Five Stages of Innovation Decision Process includes: knowledge, persuasion, decision, implementation, and confirmation (Ko et al., 2007). Moreover, based on Rogers's classification (See Figure 2.6), technology adopters are categorised as follows (Carr, 1999; Meade and Rabelo, 2004):

1. **Innovators:** Highly interested in technology and most willing to experiment and invest. Adopting new technologies is considered a competitive advantage.
2. **Early Adopters:** Interested in technology and sees the benefit of technology in creating solutions.

3. **Majority Adopters**: Divided into two groups in the study by Meade and Rabelo (2004):
   - **Early Majority:** The first group of the majority to adopt technology.
   - **Late Majority:** The second group of the majority to adopt technology.
4. **Laggards:** The last group to accept technology. They often do not see the importance of technology and tend to be more sceptical. Most likely they are forced to adopt.

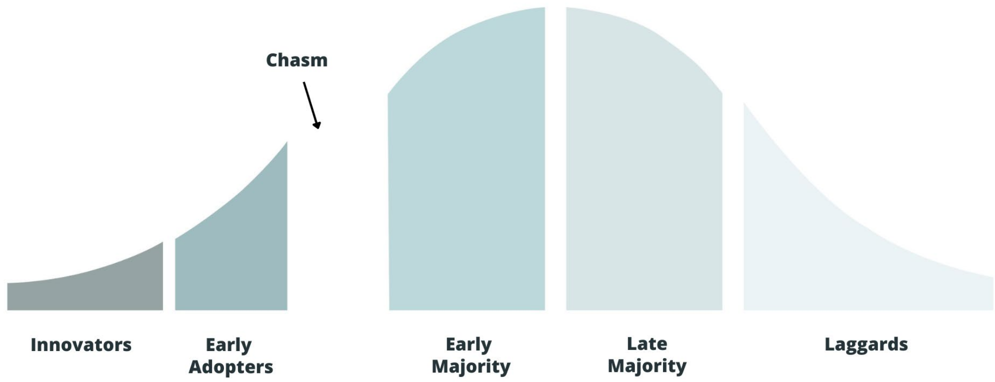


Figure 2.6 The Technology Adoption Life Cycle

Cited from Meade and Luis (2004, p. 668)

Given that this PhD study coincided with the start of the COVID-19 Pandemic, understanding the industry landscape and the adoption of digital technologies, including 3D design software, became imperative. Everett Roger's Diffusion Theory was selected to categorise participants, providing a framework to assess the industry's current state and to facilitate a critical discussion.

Complementing this approach, Daves' TAM, based on Fishbein's 1967 motivational model in the field of behaviour psychology (Daves, 1986), enhances understanding of the acceptance process of 3D design and other digital technologies in the effort of digital transformation. By focusing on the motivations for technology adoption and the transition to digital transformation, the TAM model guides the PhD methods exploring participant behaviour and motivation.

There are several other technology adoption and diffusion theories that are relevant to this study such as:

- Theory of Planned Behaviour (TPB)

- Social Cognitive Theory (SCT),
- Technology-Organisation-Environment (TOE)
- Diffusion of Complex Innovations

While various theories on technology adoption offer valuable insights within social and behavioural psychology, this PhD primarily focuses on understanding the practical applications of virtualisation within the fashion and apparel/garment sector. Therefore, DOI and TAM theories are selected as sufficient and appropriate frameworks to explore the PhD question and objectives. This study recognises the significance of the various theories, while acknowledging that in-depth exploration of social and behavioural aspects are beyond the scope of this study. Future research could further investigate these theoretical frameworks within the context of technology adoption in the fashion industry.

2.3.2 The Hype Cycle – technology promise vs reality

A more recent technology adoption model is Gartner's Hype Cycle, introduced by consultancy group Gartner in 1995 (Linden and Fenn, 2003). The model adds another dimension to Roger's diffusion of innovation model. It depicts the pattern in which most technologies gain mainstream attention, resulting in 'overenthusiasm and disillusionment' to highlight human attitudes (See Figure 2.7). The Hype Cycle occurs in the early life cycle of technology adoption and serves as an educational tool to foster critical judgement in the decision-making process. The curve mitigates over expectations of new technology by acknowledging the hype of the mainstream possibilities of new technology (Linden and Fenn, 2003).

The Hype Cycle is often discussed in the context of IT within the field of Technology and Innovation Management (TIM). However, Steinert and Leifer (2010) argue that the model needs further theoretical backing to support its use, as it is predominantly found in industry literature rather than academic sources. The model is designed from an 'organisational standpoint' (Dedehayir and Steinert, 2016) by consultants to speed up the decision-making process (Steinert and Leifer, 2010).

This PhD observes the fashion industry's uptake of virtual technologies and focuses on contemporary industry practice. The Hype Cycle is considered in this study, as consultant firms like Kalypso use it to understand the adoption of virtual technologies in the fashion industry. Moreover, the COVID-19 pandemic has accelerated the uptake of 3D design technologies; therefore, it is appropriate to include this topic.

The Hype Cycle – technology promise vs reality

The *Hype Cycle* is an analytical investment instrument produced by the consultancy firm Gartner that tracks the expectations of a technology over time.

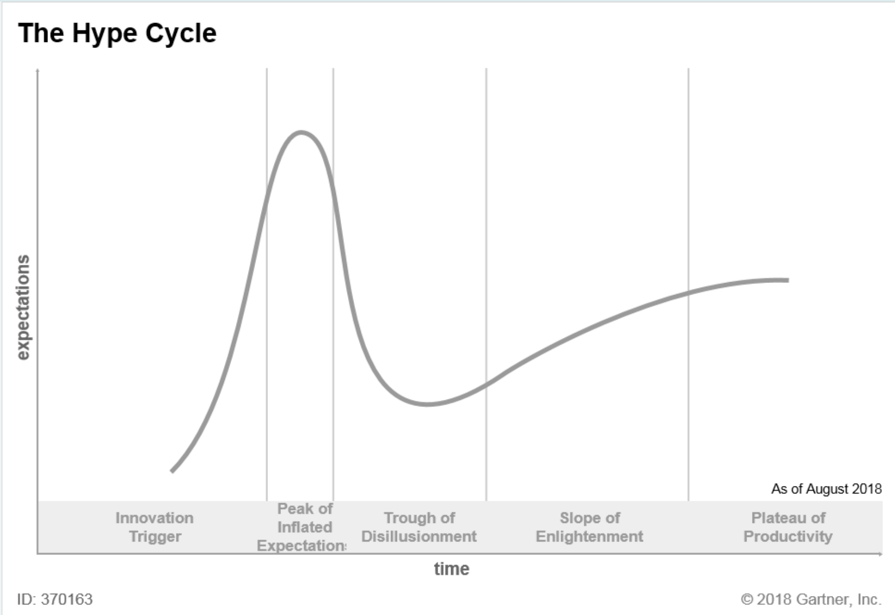


Figure 2.7 The Hype Cycle (©2018 Gartner, Inc.)

Technologies climb to the *"Peak of Inflated Expectation",* before passing into the *"Trough of Disillusionment"* and then slowly rising to a plateau. Human-centred design negates the bias of technology-hype, recognising that innovation may take many forms — a new or improved product, service, process, or communication design — all of which may or may not involve technology.

2.4 A history of innovation – the Jacquard Loom

Due to the heavy reliance on manual labour and processes, the fashion industry can be viewed as low-tech in comparison to other design and manufacturing industries. Nevertheless, historically the garment and textile industries have been at the forefront of technological innovation – mainly evident within textile production (Coughlin, 2001). Patented in 1804, Joseph-Marie Jacquard's invention of the

Jacquard Loom would transform textile production – along with underpinning a framework for contemporary computers and automation (Essinger, 2007).

Traditionally, to weave patterns into fabric, the process was carried out by ‘drawboys’ – a weaver’s assistant who manually operated the warp threads by lifting and lowering them. The Jacquard Loom automated this process making it more agile. In addition, the technology allowed for:

- Mass production– access fashionable decorative silks and fabric
- Flexibility– extensive design possibilities
- Speed– up to 24 more times faster than the traditional draw loom

Patterns were hand painted in a series of grids and punched out on ‘punch cards’. The punch card programming technology inspired Charles Babbage who later created the first computer– establishing information technology. The concept of images made up of small dots is still found in modern computing, as pixels make up digital images (Essinger, 2007).

Despite the benefits of the Jacquard Loom, some groups perceived the technology as a threat because it could potentially replace workers. Master weavers, having undergone years of extensive training, protested by throwing their shoes – called sabots – into the looms to temporarily stop production. The term *‘sabotage’* originates from this event. The technology, however, led to a different role for the weavers. Because punch cards fed the design information to the loom, someone needed to control the loom and shuttle. Over time, the innovation was apparently well accepted (Essinger, 2007).

2.4.1 First, Second, and Third Industrial Revolutions

Furthermore, the fashion industry has been a key industry in the transformation of each industrial revolution. Between 1760-1830, the First Industrial Revolution was the beginning of mechanisation of processes within production – creating the steady demand for refilling products (Nobile et al., 2021; Duarte et al., 2018). Production was powered by water and steam (Bertola and Teunissen, 2018), and technologies such as the flying shuttle, Spinning Jenny, carding machine and the Jacquard Loom was the start of automation and mass production for the fashion and textile industry (Duarte et al., 2018).

The Second Industrial Revolution was fuelled by electricity, which advanced processes (Bertola and Teunissen, 2018). A defining technology for the industry was the commercialisation of the domestic sewing machine patented in 1851 (Duarte et al., 2018). Other key technologies include John Thorp’s invention of the Ring Frame and circular knitting machine.

The Third Industrial Revolution, also known as the 'Digital Revolution', is important in this study as it introduces digital and communication technologies. As a result, these technologies reshaped mass production and allowed for the complexity of the global fashion supply chain. With open trade opportunities between countries, globalisation reshaped the traditional manufacturing process. For example, the U.S. saw most production disappear, and third-party contractors were removed from the supply chain (Bertola and Teunissen, 2018). The adoption of digital technologies, including higher computer capacity, reduced production costs. The diffusion of ‘digital logic circuits’ marked the onset of the Information Age and information technology (IT) (Duarte et al., 2018). Initially referred to as the IT Revolution, the Third Industrial Revolution gained momentum in the 1970s (Lee, et al., 2018).

2.4.2 The Fourth Industrial Revolution

The diffusion of information technologies (IT) during the Third Industrial Revolution set the foundation for the Fourth Industrial Revolution (Lee et al., 2018). Industry 4.0 paradigm has become a prominent topic in academia, industry, and governmental discussions. According to Bertola and Teunissen (2018; pp. 353), the Fourth Industrial Revolution is, *“...a model where new modes of production and consumption will dramatically transform all major industrial systems; it has been targeted by many governmental plans as a goal for a sustainable future.”* Lee et al. (2018) defines the Fourth Industrial Revolution as a transformation driven by disruptive technologies, such as artificial intelligence, automation, and hyper-connectivity, impacting both industries and societies.

Coined by Chairman Klaus Schawb at the World Economic Forum in 2016 (Prisecaru, 2016), this revolution is alternatively referred to as Industry 4.0 or the

Second Information Technology Revolution (Lee et.al, 2018). As seen in Lee et al. (2018) the term and objectives might be different depending on the country such as follows:

- USA: Advanced Manufacturing Partnership 2.0
- Germany: Industry 4.0 platform
- Japan: revitalisation/ robotics strategy
- South Korea: Manufacturing Innovation 3.0

As explained by Lee et al. (2018), the First and Second Industrial Revolutions focused on creating a cutting-edge physical space, while the third focused on developing cyberspace. The Fourth focuses on the combination of both the physical and digital. Industry 4.0 is comprised of six design principles such as follows:

- Interoperability
- Virtualisation
- Decentralisation
- Modularity
- Service Orientation
- Real-time-capability

Moreover, Lee et al. (2018) argue that evidence of the Fourth Industrial Revolution exists across many industries; however, the authors also highlight academic scepticism regarding whether it is truly occurring or merely a marketing tactic. Unlike the previous industrial revolutions, Duarte et al. (2018) explain that the current moment only allows for speculation about this phenomenon.

2.5 Industry 4.0 paradigm for the fashion industry

The Fourth Industrial Revolution is predicted to impact all manufacturing industries – including the fashion industry, a major producer of mass-produced goods. Researchers and industry experts anticipate that the Industry 4.0 paradigm will offer solutions and benefits to revolutionise the fashion supply chain and industry infrastructure (i.e. Bertola and Teunissen, 2018; Duarte et al.,2018).

The fashion industry is associated with several environmental and social issues. Business models such as fast fashion have resulted in significant environmental, social, and business implications. According to the European Parliament (2024), the fashion industry accounts for approximately 10% of global carbon emissions, and only 1% of used clothes are recycled. Additionally, textile fibre production has nearly tripled since 1975 (European Environment Agency, 2023). Fast fashion is primarily responsible for the negative environmental impact, as it accelerates consumption by quickly introducing new trends to the market. Furthermore, the fashion industry has a considerable social impact. In Europe alone, the textile industry employs 1.7 million people. Out of approximately 3,500 chemicals, 750 are identified as hazardous for human health (European Environmental Agency, 2023).

Sustaining business in a competitive market amidst political uncertainty poses additional challenges for brands. Social media, access to product knowledge, and an oversaturated market (Niinimaki, 2013; Haworth, 2015), have forced brands to reconsider new business strategies to retain and gain customers as consumers become more selective (Nayak and Padhye, 2015). These factors can often encourage early markdowns to beat competitor prices (Sherman, 2018). The proliferation of information and pressures to reduce lead times and lower costs also add to the complexity (Papahristou & Bilalis, 2017). Moreover, brands will need to balance business strategies with compliance with new environmental legislation.

Environmental, social, and government issues are the main priority and challenge of the fashion industry (McKinsey & Company and Business of Fashion, 2024). In addition, regulation, and policy, including resource use and environmental impact taxes, companies will be held accountable and required to restructure their processes to ensure transparency (European Environmental Agency, 2023). Due to a disconnected and complex supply chain, many brands are unable to trace their product life cycles (McKinsey & Company and Business of Fashion, 2024). Digitalisation is part of the EU's action plan towards a circular economy (European Environment Agency, 2023). A strategy to hold companies accountable to minimise their carbon footprint, is to introduce Digital Product Passport (European Parliament, 2024). Therefore, digital solutions are predicted to allow for faster decision making, the creation of functional products to meet consumer needs, and guide the responsibility of social and environmental standards (Duarte et al, 2018).

2.5.1 Industry 4.0 Technologies and Principles

Industry 4.0 related technologies are relevant for this study as virtualisation is one principle of the paradigm (See Table 2.2). Particularly, these technologies are to support back-end operations for a more agile and transparent supply chain (Arribas & Alfaro, 2018), and to drive digital transformation for the fashion industry to overcome key issues (Nobile et al., 2021). Bertola and Teuinssen (2018) suggest if carried out properly, digital transformation has the potential to reshape the industry to be more customer-driven, environmentally responsible, and socially conscious. Experts consider digital transformation to be the greatest competitive advantage for start-ups (Lee et al., 2018).

Industry 4.0 Technologies	Definition
Cyber- Physical Systems (CPS)	When physical environments, engineering systems, and information technology become interconnected. Each process is then, *"assessed, coordinated, controlled and integrated by a technology and communication system"* (Duarte et al., 2018, p.195).
Internet of Things (IoT)	The connection of physical items or devices to one another through sensors and actuators to computing systems to collect data from a set environment (Paphristou et al., 2017). Also known as "intelligent systems" (as seen in Duarte et al., 2018).
Big Data Analytics	A high amount of *quality* information collected and processed between a variety of sectors and successfully integrated during the product development process (Chandler, 2015; Duarte et al., 2018).
Artificial Intelligence (AI)	An area within computer science that examines human intelligence, and how machines can mimic human logic. Often the term machine learning is used interchangeably with AI; however, it is an *'application of artificial intelligence'* (Luce, 2018, p.17)
Cloud Based Computing	A group of computing resources available to access on-demand with little interaction required from the service provider (Giannakis et al., 2019).
Automation	Process carried out automatically to complete tasks using machines (Luce, 2018).

Blockchain	A *'digital ledger of transactions'* where information cannot be created or destroyed to allow for: trust, transparency, resilience, scalability, security, autonomy (Viriyasitavat et.al., 2018, p.1740).
General Technologies to support Industry 4.0	**Definition**
Radio-Frequency Identification (RFID)	Technology which enables interaction with consumers within a retail space, and to protect against counterfeit goods (Bertola and Teunissen 2018). The technology can also be used to store electronic data on the garment (Nayak and Padhye, 2015).
Product Lifecycle Management (PLM) Software	A tool that guides the planning and development of a product and manages its data throughout the product life cycle (Arribas and Alfaro, 2016).
3D design technologies	A variety of digital technologies which allow to carry out a process in 3D such as (Kim et al., 2020): 3D pattern making, 3D scanning, 3D virtualisation, 3D printing production.

Table 2.2 Key Technologies of Industry 4.0
Cited from multiple authors.

According to Bertola and Teunissen (2018), some of the foundational digital technologies are established within the industry– such as RFID, PLM software, 3D design technologies – to accommodate interconnectivity or virtualisation of the complete value chain. Software programs such PLM manage time and garment information in an all-encompassing platform. Traditionally, excel sheets are used to manage and share product information. Senanayake (2015) explains PLM software provides valuable data for brands to know what is selling. This in turn would allow the right amount of inventory for a particular season to be planned before producing. According to Hines (2004), inventories make up 50-60% or more of manufacturing balance sheets. Additionally, the Industry 4.0 framework allows for the participation of the consumers during the production process and the integration of CPS and Big Data (Duarte et al., 2018).

2.5.2 Smart Factories

An objective of the Industry 4.0 paradigm is to transform traditional factories and manufacturing into *'smart factories'*, defined as *"a network of flexible decentralised* *manufacturing and service units"* (Bertola and Teunissen, 2018, p.360). Smart factories would allow flexible manufacturing by decentralising units of manufacturing and services to support as follows (Bertola and Teunissen, 2018):

- Real-time data exchange
- Quick amendments
- Confinement of issues
- Lessening the impact to one unit instead of the system.

An important piece of literature is the article by Bertola and Teunissen (2018). The researchers utilise the six design principles of Industry 4.0 and the smart factory model to analyse the garment and textile sectors, identifying key operations, business sectors, and related Industry 4.0 technologies (See Figure 2.8). Achieving the benefits of an interconnected and fluid structure requires business ecosystems to integrate new technologies for seamless data exchange at all levels of the supply chain. This integration promotes transparency, efficiency, leanness, and responsiveness to customer's needs (Bertola and Teunissen, 2018).

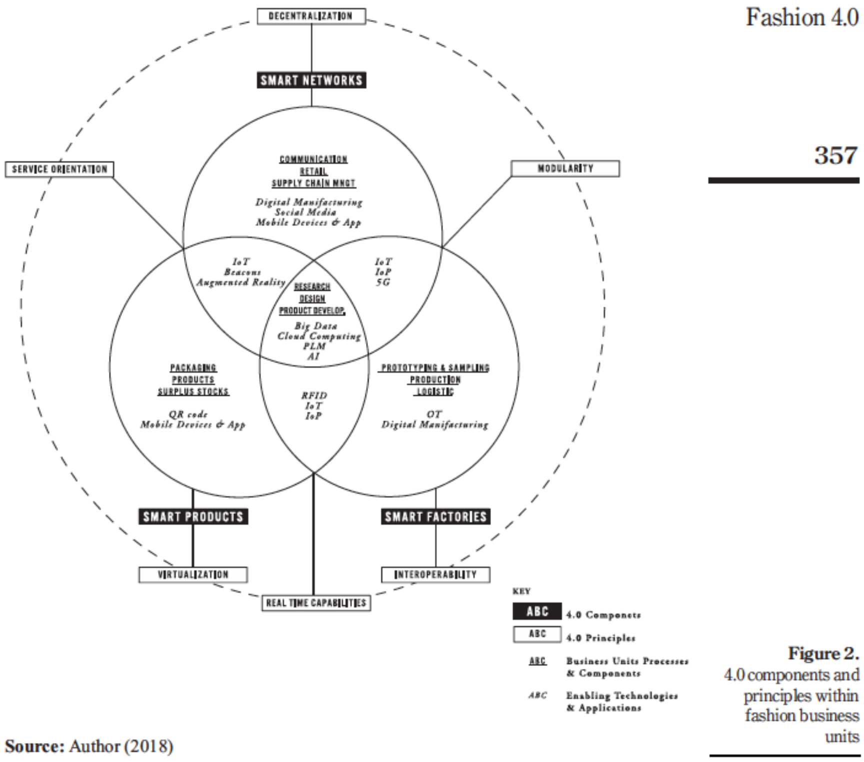


Figure 2.8 Industry 4.0 Components and principles within fashion business units Cited in Bertola and Teunnissen (2018, p.357).

2.5.3 Challenges of Industry 4.0

The fashion industry would benefit greatly from Industry 4.0; however, there are many challenges regarding the practicality of implementation. Firstly, the industry's uptake of technologies is slow compared to other design and manufacturing industries where digital foundations have been established over time. According to Bertola and Teunissen (2018), the fashion industry lacks crucial structural components such as the six principles of Industry 4.0 and standardised business processes. Coughlin et al. (2001), highlight that the textile sector leads in technological development and capital investments compared to the garment sector, which relies more on cheap manual labour. Fashion for Good (2020) reports that to scale innovation, 35% of all financial support should focus on the cut-make-trim stage of production, which involves cutting, assembling, and finishing the final garments. Designs are sometimes developed in-house at firm headquarters, while other orders are outsourced to manufacturers (Coughlin et al., 2001).

Additionally, Bertola and Teunissen (2018) argue there are few organisations within the fashion industry fully embracing Industry 4.0. Despite major brands utilising technologies for virtual fashion shows and digital showrooms, technologies are not used to their full potential – but as *'communication expedients'* instead of in back-end operations purposes within garment design, development, and manufacturing.

2.5.4 The LEAPFROG Project

Despite the positive outlook of Industry 4.0 for the fashion industry, a similar initiative was carried out in the early 2000s. The Leadership for European Apparel Production From Research along Original Guidelines (LEAPFROG) project was ahead of its time, as it shares the same initiatives as Industry 4.0– such as mass customisation and personalisation. According to Freund (2008), mass customised or made-to-order manufacturing adds values for consumers– such as improving productivity in garment manufacturing resulting in efficiency, quality, and sustainable business practices. Sponsored by the European Union with a budget of 42 million euros, the LEAPFROG Project began in 2001 and was implemented in May 2005 to achieve a technology breakthrough within garment manufacturing (Coster, 2006) and give Europe's garment industry a competitive advantage, reducing the dependence on outsource labour (Freund, 2008). Bonsignorio and Molfino (2006) discuss how the project utilised the 'GALsim' system– a holistic manufacturing execution system with numerous components that can function independently or collectively. Bonsignorio and Molfino (2006, P.307) state, "*Current version of GALsim allows to simulate production management of the overall system in the different conditions envisioned at design time and to provide an operational decision support system after the facility deployment."* Coster (2006) highlights the level of complexity of the project by referencing a similar project carried out in Japan in the late 1980s in efforts to reduce time by automating garment manufacturing. With a budget of 20 billion yen, the project failed (Coster, 2006).

The research conducted by the LEAPFROG Project found a reduction of physical samples as a result of 3D virtual prototyping and many opportunities for further development (Coster, 2006). However, there were many shortcomings of the LEAPFROG project such as the following (Coster, 2006; Freund, 2008):

- Garment design is highly regarded as an artistic process.
- The type of data or information is difficult to transfer across technologies and teams. Over 70 organisations involved in the program lacked connectivity of technologies for streamlined processes.
- According to Freund (2008), the project did not take into consideration the interaction of humans and computers as many stakeholders were apathetic towards utilising computers.

The project ended in 2009 as a result of these shortcomings. Interestingly, this project occurred nearly 15 years ago with promises of a high-tech garment manufacturing system. The same challenges identified remain to date. The difference is, technology has advanced since 2009, and the COVID-19 pandemic became a catalyst.

2.6 Summary of Chapter 2

This section provides a summary of *Chapter 2: Literature Review*, which has laid the groundwork for the PhD methodology and understanding of the topic. This literature review explores the uptake of technologies within the fashion industry, provides an overview of the current state of the industry, and delves into themes relevant to answering the PhD research question.

The chapter begins with a general overview of the inner workings of the fashion industry and the garment product development process for context. It then discusses fashion market segmentation to show how the industry organises goods into tiers of product differentiation to meet different target groups. This observation is important as the market segment affects the decisions in the adoption of virtual technologies.

Furthermore, finding relevant literature on the uptake of digital technologies in the fashion industry was challenging due to the lack of literature specifically related to design and product development process. However, relevant studies were found in the fields of computer science, business and retail, and supply chain management. There is extensive literature on ICT technologies and SCT. Additionally, businesses enabled by technology within fashion, such as JIT manufacturing, the fast fashion phenomenon, QR, were explored. ICT enabled these business strategies, transforming the ways garments are designed, produced, and consumed. In regard to digital technologies within the product development process, 3D digital technologies are discussed in the literature within the areas of:

- Design and modelling of 3D digital prototypes and the benefits of 3D design software.
- Education and pedagogical framework.
- Manufacturing, retail, and management strategies.
- Mathematics, computer science, and engineering of 3D design software.

Despite evidence of virtual technologies in garment product development, their uptake and adoption is lower than other design and manufacturing industries. Therefore, Everett Roger's diffusion of innovation theory is explored to categorise the industry regarding adoption, such as innovators, laggards, etc.

The fashion industry has historically been a leader of innovation and technology, as evidenced with the Jacquard Loom. It played a large role in the industrial revolutions and is predicted to be impacted by the Fourth Industrial Revolution. Also known as Industry 4.0, the literature on this paradigm in the context of the fashion industry is reviewed, as the principles and defining technologies are relevant to this PhD study.

There are a number of shortcomings in the literature on technological uptake in the fashion industry. The literature does not critically consider where along the technology adoption curve these digital technologies lie. Discussions of the Fourth Industrial Revolution predict it will transform the industry and solve some of the industry's most pressing issues. However, the literature does not critically consider the practicality of the related technologies within a conservative industry and lacks empirical research to support such paradigms. The next chapter will explore themes of craft and authenticity in relation to the fashion industry and technology as these themes continue to be contemporary topics of interest.

Chapter 3: Literature review – Fashion craft, authenticity, and technology

3.0 Introduction to Chapter 3

This chapter reviews the literature on craft and authenticity by exploring these concepts both generally and in relation to the fashion industry. The COVID-19 pandemic has significantly accelerated digital transformation and the uptake of 3D design technologies. This chapter explores the construct of technology in relation to craft and authenticity, which is relevant as virtualisation has the potential to disrupt the day-to-day process of stakeholders, such as designers, in the fashion industry.

Discussions of authenticity can be found within management journals and across a range of disciplines, leading to a variety of social constructs (Lechman et al., 2019). This chapter explores definitions and characteristics of authenticity and craft outlined in the academic literature. This provides an objective understanding and criteria to facilitate critical observations during data collection and analysis. Therefore, this chapter will explore the follow topics:

- Defining 'craft' and 'authenticity'
- Fashion, craft, and authenticity
- Parallelism of the Arts and Crafts Movement

As discussed in *Chapter 2 Literature Review,* the fashion and apparel/garment industry has historically shown resistance to technology adoption. During the COVID-19 pandemic, industry literature highlighted emerging digital technologies and discussed their role in supporting themes of craft and authenticity, providing compelling reasons for adoption. However, sceptics argue that these themes are fundamental to certain brands, particularly legacy fashion houses that value heritage and tradition – attributes that contribute to their longevity and business success. Specifically, segments such as couture and luxury rely heavily on tactile, visual, and emotional experiences. Archille (2018) suggests that acceptance of 3D design technologies may pose challenges, yet it also presents opportunities for the luxury sector (Archille, 2018). Those more in favour of digital technology argue that digital is a tool that can return craft to the designers and makers.

Furthermore, the discourse between craft, authenticity, and technology is not new. The Arts and Crafts Movement was in response to the First Industrial Revolution and the absence of authenticity and craft. This chapter begins with exploring a brief history of these themes within the Arts and Crafts Movement, setting the stage for a discussion of contemporary resistance to digital technologies within the fashion industry.

3.1 The Arts and Craft Movement

This section briefly reviews the Arts and Craft Movement in the 19th century and its lasting impact on the practises of art, craft, and design (Lee-Maffei and Sandino, 2004). Beginning with The Victorian Era, trading of goods contributed to economic growth and overall power of the British Empire (Adam, 2015). Decorating and furnishing homes with a variety of elaborate foreign objects and textiles – known as the 'Victorian Style' – was a sign of wealth. Decoration and ornamentation became the desirable style amongst the middle class. However, there was great opposition to the Victorian lifestyle. The Gothic Revival Movement was formed in response to the 'excessive' Victorian lifestyle. The Gothic Revival drew upon spiritual elements of Catholic and mediaeval times. Additionally, expressing personal identity in a mass-produced society became challenging — thereby underscoring the significance of individualism (Adam, 2015). The harsh working conditions of the First Industrial Revolution were considered 'dehumanising'. This in turn led to the Arts and Crafts Movement, which shared values of the Gothic Revival (Cumming and Kaplan, 1991). John Ruskin, a key leader of the movement, believed apprenticeship systems to teach morals of craftsmanship could solve the social issues of the time (Adam, 2015).

The Arts and Crafts Movement was not *'anti-industrial'* nor *'anti-modern.'* The underlying issue was not the technology itself, but the process in which production was carried out. Instead, reformists believed inventions or technology should be utilised to remove repetitive tasks, and that everyone has access to craft and quality products (Kapla and Crawford, 2004). Industrialisation allowed for faster production processes and affordable products for all; however, it removed individuality and compromised quality and skills through standardisation (Adams, 2015). According to

Cumming and Kaplan (1991), Ruskin believed in *'beauty of imperfection'* in that the imperfections arising from hand-crafted processes is what standardisation cannot create. However, *'one-of-a-kind'* pieces made of high-quality materials required a longer process and could only be afforded by the wealthy (Cumming and Kaplan,1991).

William Morris, also a leader of the movement and most widely known for textiles and patterns, acknowledged there is a limitation to achieving the design he envisioned for a wider audience (Adam, 2015). This in turn led Morris to recognise that commercialised design was a way to introduce his products to a wider consumer range. Morris combined craft with commerce, challenging manufacturers to work with craftsmen to simplify design to make products affordable. The result was the merging of industry and craft. Industry would turn to craft educators to train younger artists and designers to fill the skills needed by industry – in turn crafters acknowledged machines as tools. In addition, the concept of promoting 'hand-crafted' products became an important selling strategy (Cumming and Kaplan, 1991).

Key leaders of the Arts and Crafts Movement, such as Ruskin and Morris empathised with craftsmanship (Adam, 2015) and sought to merge practices of design, art, and craft (Lee-Maffei and Sandino, 2004). They advocated for equality among all creative endeavours and aimed to unify the arts to enhance the quality of both process and product. These leaders believed that the art of making should bring joy (Kapla and Crawford, 2004), and some saw Arts and Craft as a lifestyle promoting simplicity and close connection with nature (Cumming and Kaplan, 1991). The concept of *'Gesamtkunstwerk'*, meaning a complete work of art where everything serves a purpose, emerged from the Arts of Craft Movement. However, the idea itself was influenced by advancements in production techniques and materials enabled by high technology (Adams, 2015). In summary, the main ideals associated with this movement are as follows:

- Function over style
- Use of local materials so that the object reflects its environment
- Rejection of urbanisation and industrialisation

- Make it yourself

As seen above, the relationship between the Art and Craft movement and technology is a complex one.

3.1.1 Defining technology

The primary challenge in the Arts and Crafts Movement was the disruptive nature of technology. Disruptive technology is defined as a disrupter of *“an established trajectory of performance improvement”* or significantly reshaping systems and processes (Christensen and Bower, 1996, p.202). Technology carries various interpretations and can be viewed as an abstract construct (Steenhuis & De Bruijn, 2006). Lee et al. (2014, p.16) defines technology as *‘useful arts...includ[ing] all tools, machines, utensils, weapons, instruments, housing, clothing, communicating, and transporting devices and the skills by which we produce and use them*.” Clark and Estes (1998, p.5), view technology as, *“The application of science, especially to industrial or commercial objectives”,* or *“the entire body of methods and materials used to-achieve such objectives.”* German philosopher Martin Heidegger proposed a deeper connection between art and technology, suggesting that technology should not be reduced to tools but understood as a blend of art and aesthetics which captures an *‘essence’* (Rutsky, 1999). Heidegger's perspective devices from the Greek term *“techneɯ*”, which is also translated to mean art or beauty (Heidegger, 1977, pp. 34).

3.1.2 High technology

The term ‘high technology' – or ‘high tech’ – is widely used in the literature, first appearing in the 1950's in reference to a new set of postwar technologies (Miller, 1998). Rammert (1992, p.194) defines high technologies as those, “*...based on a paradigm shift from mechanical engineering to information engineering.”* Like 'technology', the term ‘high technology’ is ambiguous due to its various contextual applications (Steenhuis and De Bruijn, 2006). It may refer to industries or organisations with high levels of engineering research and development (Miller, 1998). Described as 'state-of-the-art technology', 'cutting edge' or 'leading wave', high technology must be in a constant state of evolution to qualify as high tech

(Rutsky 1999, p. 5), Rutsky (1999) argus that high technology represents advancements over modern technology, such as the shift from analogue to digital or mechanical to electronic.

The term is also used to classify or differentiate between countries based on their technological access (Steenhuis and De Bruijin, 2006). Technology facilitates standardisation and automation for improved communication and efficiency in everyday processes and productivity – a measurement of modern and advanced society (Clark and Estes, 1998). In this thesis, 'high technology' will specifically refer to technology involved in the virtualisation process.

3.2 Defining 'craft' and ‘authenticity’

This section provides an overview of the concepts of 'craft' and 'authenticity' by exploring the constructs that define them. The section will begin by defining 'craft', before going on to discuss the relationship of this term with the concept of 'authenticity'.

3.2.1 Craft– an object, a maker, and a social value

The general term ‘craft’ within the field is subjective depending on the context in which it is placed. In a study by Clark and Estes (1998), craft is defined as a special skill in which proficiency has been passed down between generations and become specialised. The authors view craft as any medium in any discipline – including the art of medicine. Craft can also be the relationship amongst many elements when it is referred to as a process or craft practice. Loh et al. (2016, p.187) define ‘craft practice’ as “...*rooted in the relationship between materials, tools and techniques as an intricate workflow*.” In addition, craft can be ‘an object’ or ‘the crafter’, which are discussed below.

An object

Craft objects are defined by how they are created, the materials used, and the appreciation for the crafting process itself (Wooley and Niedderer, 2016). They hold emotional value through storytelling, as understanding the materials, the making process, and appreciating the skill involved contribute to their significance. Craft objects often embody meaning through symbols tied to specific communities, and they may carry hidden stories about society or personal experiences (Wooley and Niedderer, 2016). Quality and individualism are intrinsic to craft products – which are often sacrificed to allow for efficiency and standardisation (Kuusk et al., 2016).

Craft objects tend to be more expensive as some consumer groups are willing to pay for the craft process as opposed to mechanised processes (Holt and Yamauchi, 2019). They can encourage touch and feel, but occasionally the expected '*feel'* of the object does not match what it appears to be (Kuusk et al., 2016). However, craft objects often reflect their environment. Most importantly, the object *appears* to be what it is– not a 'representation' of another object (Holt and Yamauchi, 2019).

The 'crafter'

A consistent theme in the literature on craft is 'the enjoyment' experienced from the process of making and the care that goes into it (Wooley and Niedderer, 2016). Craft literature also emphasises the knowledge, skills and qualities demonstrated by those engaged in craft work. 'Crafters' – people who undertake craftwork – exhibit mastery of the craft medium and derive satisfaction from their work (Kuusk et al., 2016). Holt and Yamauchi (2019) highlight apprenticeship and specialised training in craft practice, highlighting the high skill level required, which distinguishes crafters from hobbyists. The requirement of a high level of skill is what sets a 'crafter' apart from a 'hobbyist' (Lee-Maffei and Sandino, 2004; Cumming and Kaplan, 1991).

Kuusk et al. (2016) further explain that a crafter's relationship with materials creates value in the process and its output. Additionally, Hold and Yamauchi (2019) argue that materials offer potential for the crafters to explore and discover the intended shape of the material based on its qualities. The embrace of uncertainty and continual risk-taking by practitioners adds value to craft objects, setting them apart from mass-produced items. Holt and Yamauchi (2019, p.23) states,

> *Craft preserves and works with the possibility of failure, and it is in this dark space that a sense of human complicity and responsibility for what becomes a distinct and distinctive thing takes root. In short, craft craves and needs risk, whereas design can and often does reach for certainty.*

Social element of craft

Social elements of craft are heritage, tradition, and community. The study by Kuusk et al. (2016) highlights a number of ways craft creates social values as follows:

- Provides connection to the family unit through storytelling or might result in 'community openness'.
- Honours heritage and tradition through passed down skills through generations.
- Represent a society in a specific time and place– might have aspects that an outside culture might not fully understand.
- Evolves over time as environments and ideas of the society change.
- Has a connection with nature and its natural environment.

Holt and Yamauchi (2019) discuss the importance of craft in cultures, using contemporary Japan as an example. Western influence has reshaped Japanese culture and values, and in some ways, tradition has been lost. However, this study highlights human desire to find tradition once more. This suggests there is a need for authenticity and craft in our daily lives and relates to the construct of returning to our 'true selves'.

3.2.2 Defining authenticity

The concept of authenticity is often associated with craft. Loh et al. (2016) suggest the authenticity underlies the complexity of the use of a range of tools and techniques coupled with other systems in which the social and cultural meaning is drawn. According to Wooley and Niedderer (2016), craft contributes to authentication through:

- The exchange of knowledge between both maker and the audience.
- Traces of the crafter's skills which are visible in the resulting object.
- The influence of the original environment on the craft object.
- Quality and genuineness, with each piece being slightly different.

Authenticity is challenging to define as it is an abstract concept and subjective in the context in which it is placed. Drawing upon the work of Philosopher Soren Kierkegaard, Su and Stolerman (2016, p. 643) define authenticity as: *“A mode of existence arising from self-awareness, critical reflection on one’s goals and values, and responsibility for one’s own actions; the condition of being true to oneself.”* The concept has been researched across multiple disciplines and social constructs (Newman, 2019). However, researchers have identified a common theme associated with authenticity which is what is ‘genuine’, ‘real’, and / or ‘true’ – factual and is what it appears to be (Newman, 2019; Lechman, et al, 2019; Keiningham, et al., 2019). As a result, verification is part of the authentication process (Lechman, et al., 2019).

3.2.3 Demand for authenticity, craft, and innovation in globalised society

Globalisation and mass production have challenged ownership of craft practices and their use. In Wooley and Niedderer (2016), the authors discuss what authenticity in craft means within the digital age, and the challenges it brings through different artist’s experiences. Technological innovation, such as computer aided manufacturing (CAM) and creating craft through science, challenges the meaning of craft – particularly in the making process in relation to hand making and the originality of the object. As a result of digital technologies enabling globalisation of the production of goods, the place of origin becomes unknown, and the authentication is blurred. Moreover, designers gain recognition for their work and compensated for their contribution; however, crafts people are not often paid and struggle financially as they remain anonymous (Wooley and Niedderer, 2016).

In addition, the diffusion of digital communication and globalisation has provided consumers with the ability to search and explore their identity– influencing their purchase behaviour (Keiningham et al., 2019). This in turn creates a demand for products to match their identity and encourages rejection of standardised products. According to Newman (2019), authenticity drives consumers to purchase products and services across a variety of industries as well as influences their judgement and behaviour. For some, ‘authentic living’ (Su and Stolterman, 2016) or ‘moral authenticity’ (Newman, 2019) has become a lifestyle of individuality.

For businesses to stay competitive, products and services must be 'authentic' or 'unique' according to Keiningham et al. *(*2019) as they become a prerequisite in the decision-making process. To achieve this, organisations must determine what their customers perceive to be 'authentic'. However, retaining their existing customer base while trying to gain new shares in the market is challenging. Brands would need to consider how to maintain their heritage while innovating to evolve with consumers. However, these are conflicting constructs as innovation moves away from the past. Whereas authenticity is linked to consistency over a period (Keiningham et al., 2019). Consequently, the risk of being perceived as less authentic is a challenge for firms that are driven by innovation.

Innovation is a term often viewed as a buzzword in management literature (Keiningham et al., 2019). Authenticity has also gained much attention within this field, as consumers often associate a company's goods, services, or experiences with authenticity. Organisations must consider the benefits of innovation. Being authentically innovative entails focusing, *"...on being themselves and work on innovations that reflect and positively extend their fundamental values and identity* (Keiningham et al.,2019, p. 379)"*,* as opposed to following innovation trends.

Technology is part of modern society, and Su and Stolterman (2016) suggest that technology might be disrupting authentic living by hindering communication skills, replacing traditional practices, and disconnecting society and nature. In the field of *Human Computer Interaction* research, the authors discuss how authenticity often rejects technology. However, Su and Stolterman (2016, p. 652) suggest that *"Designing for authenticity allowed us to understand the ways in which we try our best to live fulfilling and worthwhile lives with technology."*

Referencing the traditional craft section above, craft itself values sustainability in the way in which tradition develops over time. Craft as '*tradition'*– not within the last 10 years– is considered contemporary. Craft as an '*activity'* does not remain in the past but requires innovation of crafters' techniques as the lifestyle of the crafter evolves with time. Craft represents the community and is a direct link to that culture in which the products are created through local materials (Kuusk et al., 2016).

3.3 Fashion, craft, and authenticity

In this chapter so far, themes of craft and authenticity have been explored within a more general context. This section is developed in a subsequent version of *Chapter 3* and seeks to understand values of craft and authenticity in relation to the fashion industry and technology. These themes continue to be contemporary topics of interest (e.g. Armitage, 2023; Huggard and Sarmakari, 2023). According to Bertola & Teunissen (2018), customers are searching for authenticity and uniqueness in 'real' craft products, which demonstrate true artistry. Additionally, these themes allow understanding of the fashion practitioner's identity and the impact of new technologies on their processes and required skills. Discussion of the Arts and Crafts Movement provides historical context to the contradictory nature of technology and craft in which parallels can be drawn to the contemporary conflict within the Fashion Industry's uptake of high technologies. These similarities are discussed in the next section.

3.4 Parallelisms of the Arts and Crafts Movement and Industry 4.0

Traces of the Arts and Crafts Movement are still evident within contemporary issues – especially in regard to the fashion industry. Adams (2015) suggests the movement has not fully disappeared. Instead, the influence of the Arts and Crafts Movement has evolved and remains the core of design. As discussed previously, leaders of the movement aimed to combine art, design, and craft. The difference between craft and design – and even art, craft, and design – is an ongoing debate in the academic literature (as seen in Clark and Estes, 1998; Holt and Yamauchi, 2019). Holt and Yamauchi (2019, p.22-23) defines 'design' as, *"…the projection of ideas and feelings through representation"*, and 'craft' consists of,

> *...embodied work, which cannot be represented…It [Craft] is quieter than design, looser in conscious direction, and perhaps less in thrall to the idea of being distinct and noticeable. Craft is about things, whereas design is about objectified things, or objects.*

The Arts and Crafts movement was a response to industrialisation and the social impact it created – both negatively and positively. In contemporary society craft can be seen as an *"... antidote to industrialisation"* (Lee-Maffei and Sandino, 2004, p.

209). Parallels can be drawn between the desire for the reformation of craft, authenticity, and technology of the Arts and Crafts Movement and once more with the Fourth Industrial Revolution – or ‘Industry 4.0’.

As discussed in *Chapter 2 Literature Review*, The Fourth Industrial Revolution is targeted by governments to incorporate high technologies and related strategies to reshape all major industries – in part as a response to demands for more environmental and business sustainable practices (Bertola and Teunissen, 2018). The technology defining Industry 4.0 is projected to reshape working organisations and create new ways of living – just as the technology did in the First Industrial Revolution. For example, technologies such as the Internet of Things (IoT) allow for faster and direct communication with other technologies resulting in faster processes in logistics and removing mundane tasks.

Sourcing locally is another characteristic in the Arts and Crafts Movement, with value placed on the ‘truth in materials’ in which imitation of a material was seen as dishonest (Adams, 2015). Utilising local materials for the object to reflect its environment is a similar craft value of the paradigm shift of ‘nearshoring’ and / or ‘reshoring' to source locally and to serve nearby consumers.

3.4.1 Democratisation of fashion– Mass customisation

Similarly, the idea of arts and crafts for all to enjoy, supports the fast fashion business model where all have access to trends. According to Mustonen (2013, p.14), *“Democratisation of fashion refers also to the industrialisation of fashion…Because fashion does not come from one particular source, its overall essence can be portrayed democratic.”*

In the regards to the paradigm shift of the traditional fashion system, open-source fashion is an area of study gaining much research interest along the fields of philosophy (i.e. Mustonen, 2013) and in relation to fashion sustainability (i.e. Smith et al., 2017; Scaturro, 2015). New discussions of virtual technologies enabling democratisation within the fashion design process has become a growing area of research. For example, Huggard and Sarmakari (2023) explain blockchain and token-based technologies have enabled ‘digital fashion’. This has led to new relationships between fashion and consumers through a decentralised system – allowing the consumer to take part of the design and ownership (Huggard and Sarmakari, 2023). A predicted outcome of the Industry 4.0 paradigm is to enable mass customisation for the customer to participate.

3.4.2 The ‘digi-physical’ – a digital fashion craft

A digital craft is emerging through a mixture of traditional craft along with digital technologies as an initiative to keep craft in circulation within contemporary practice. ‘Smart technologies’ and advanced technologies– merging both technology and craft– enable opportunities for new values, garment functionality, and storytelling (e.g. Kuusk et al., 2016; Townsend and Niedderer, 2016). Regarding brands, as discussed previously, new mediums of digital showrooms and 3D virtual assets emerged during the COVID-19 pandemic. The term ‘digi-physical’ or ‘phygital’ has emerged within academic and industry literature regarding the creation of garments in blending the digital and physical worlds (Chen, 2023; The Digital Fashion Group, 2023). Lee-Maffei and Sandino (2014) argues that both hand-made or made with high technology to create innovation can be considered craft. Based on the literature discussed at the beginning of this chapter, digital fashion fits the criteria of ‘craft qualities’. For example:

- Eliminates mundane tasks such as physically making samples.
- Allows precision of craft by virtual prototyping to see outcomes in real-time.
- Supports environmental sustainability by reducing waste in the pre-production stage.
- Supports creativity and innovation by removing hesitation in experimentation.
- Requires skill and understanding of the crafter to convert the physical to a digital twin.

Virtualisation might contradict the principles of authenticity of what is real and genuine as it represents a physical process. Moreover, utilising virtual prototypes within virtual platforms (i.e. as seen in Hobbs, 2020) for marketing could be considered inauthentic.

However, one can argue it is the intention placed behind the practice. For example, designers at The Fabricant – the first 'digital only' fashion couture house – still undergo a creative process, but the production of the final garment is digitally created rather than physical. Furthermore, a 'digital twin' should be an exact model of the physical. Kritzinger et al. (2018, p.1016) defines digital twin as *"a digital informational construct about a physical system, created as an entity on its own and linked with a physical system in question."* Additionally, the digital twin should include data of the physical model if it is to be used in the physical world.

In *"The Authentic Digital Garment"* talk during the 2020 3D Tech Festival, Jason Wang, CEO of Alvanon, emphasised *'garment authenticity'* (Wang, 2020). Wang explains developing *'trust'* that the digital garment is as exactly as the physical garment is an essential of acceptance of digital garment twins. As a result, this would eliminate the guesswork that comes with physical prototyping. The topic of digital twins has become of high interest in research specifically within general literature of manufacturing industries and Industry 4.0 (Kritizinger et al., 2018; Bao et al., 2019) – or within architecture (e.g. Bastos, 2021) on the topic of building information modelling (BIM) and building energy modelling (BEM).

3.5 Resistance of high technology within luxury

Chapter 2 Literature Review highlighted technology resistance in discussing the invention and the diffusion of the Jacquard Loom. However, there are other examples of resistance to high technology within garment production. According to Nayak and Padhye (2015), in 1830, the first garment manufacturing company to include machinery was founded by French inventor Barthelemy Thimonnier to produce army uniforms. In fear of being replaced, a group of tailors broke into the factory, destroyed the machinery by throwing it out the windows, and continued to burn down the site (Nayak and Padhye, 2015). This fear of new technologies is still evident within discussions around contemporary industry practices even within a digitally driven society. In Lee-Maffei and Sandino (2004, p. 210), the authors state,

> *Despite a pervasive cultural preoccupation with media and digital technology, the earlier enthusiasms and fears that characterised the machine age, and continuing discussion about the role of CAD in the crafts, contemporary visual culture displays a continuing concern for spiritual enlightenment through consumption…*

Although this PhD study is not focused on the haute couture sector, it is important to acknowledge discussions around digital technologies placed within this context as the sector influence trickles down the fashion pyramid. (See Figure 3.3). Haute couture and high-end luxury houses prioritise artistry and craftsmanship over the practicality or functionality of design. Haute Couture is distinguished and celebrated for its genuine innovation and craftsmanship, unlike commercial designs that often replicate the original (Ferrero-Regis, 2008).

With the adoption of digital technologies virtualisation within contemporary industry, the debate about the potential impact has again been highlighted. The same fears of automation replacing manual processes resulting in job loss is valid. Once more the desire for quality and authenticity is being demanded, but the addition of mass customisation as part of Industry 4.0 is a contradiction, as high technologies would need to be part of the equation to support this model. Additionally, organisational culture and the way in which work is carried out has been highlighted to be dramatically transformed (as discussed in Cumming and Kaplan, 1991). In turn, this might raise questions on how this will impact stakeholders and their own processes within the workplace. This section will explore the discord of virtualisation and haute couture, and to understand the rationale of a designer's identity.

3.5.1 The discord of physical and digital in haute couture

The relationship between digital and physical is conflicting given the nature of garment creation. The craft of making fashion goods is highly tactile and based on emotion (as seen in Hirvonen et al., 2016). Given the history of haute couture, this segment is most likely to resist change of traditional industry practices through the uptake of digital technologies.

Armitage (2023, p.129) argues the practice and idea of haute couture *cannot* be *"managed or computed within a fixed horizon".* The author concludes haute couture within virtualised spaces, like the Metaverse, can no longer be considered haute couture as the hand craft of sewing is obsolete. Moreover, digital haute couture allows a mass group of customers to enjoy the craft as opposed to a *"small elite group"* (p.137). Armitage (2023) argues that the disappearance of haute couture concepts and history is a result of the fashion industry's dependence on digital technologies and the uptake of virtual technologies amongst haute couturiers. Armitage (2023; p.133) states that haute couture is "*a source not merely of sales and making money, publicity, and luxury branding, but also of meaningfulness.*"

Despite this to be true in regard to haute couture having the freedom to be as grandiose and unconventional, one might argue even haute couture is limited within the boundaries of a capitalism as haute couture is not only art. Interestingly, Ferrero-Regis (2008) argues 'designer-name' is simply a way to market products to sell an alluring construct of a particular lifestyle – in which haute couture can be argued as simply a marketing strategy of creating product differentiation. In addition, this goes against the concept of authenticity by creating a false reality of a concept of art as opposed to design.

Both Armitage (2023) and Ferrero-Regis (2008) emphasise the importance of the crafter or couturier and their participation within the process and raise concerns for the practitioners. Moreover, Ferrero-Regis (2008) acknowledges digital technologies might result in removing the designer as it removes the tactile work for more efficient processes to support mass production. This rejects individualism; however, the author highlights that within haute couture and brands, '*invisible designers*' are working endlessly in the background of the praised designer (Ferrero-Regis, 2008). This in turn contradicts concerns around the designer as the production of garments require a team of skilled professionals – who go unacknowledged.

As a result of the travel ban during the COVID-19 pandemic, brands rushed to find an alternative to the traditional presentation of physical runway shows. Many brands turned to virtual fashion shows, video games, virtual showrooms, and digital look books (e.g. Yotka, 2020; Schaer, 2020). In addition, the NFTs and Metaverse hype became mainstream (e.g. Fairey, 2023). However, high end brands were not so eager and made it clear to continue with their long-standing heritage to focus on physical goods. For example, in an article by Vogue Business, Bernard Arnault, Chief Executive at LVMH stated (Milnes, 2022, p.2),

> *We have to see what will be the applications of the Metaverse and NFTs…It can undoubtedly have a positive impact – if it is well done – on the activity of the brands, but it is not our objective to sell virtual sneakers at €10. We are not interested in that.*

For couture and high-end luxury, the statement above is a valid response, as their customers pay for the craftsmanship of a physical product. As seen in the study by Keiningham et al. (2019), by creating authentic brand ideology, a firm can establish a relationship with consumers by offering unique products with a strong association with history, a specific setting, or attitude. Additionally, the article provides an example of an organisation not rushing to follow a trend as it does not meet their values. Interestingly, however, Milnes (2022) draws attention to the flexibility and financial freedom brands would need to invest in technologies at any given time. LVMH reported €64.2 billion in annual revenue for 2021. Arnault is not fully saying no to these virtual solutions but is more cautious. However, some luxury brands such as Balmain and Gucci are investing in virtual solutions, i.e. Metaverse and NFTs, to cater for a younger demographic. Milnes (2022) explains that some brands might purely see participation in virtual worlds such as the Metaverse or video games for marketing opportunities rather than back-end operations. The article is an example of criticising interactive virtual technologies for entertainment but does not critically consider how digital technologies could support contemporary haute couture practice.

3.5.2 Ideals of romanticism– a designer's identity

In the 1800s, the ideals of romanticism led designers to identify as 'artists' and to celebrate individualism in response to the Industrial Revolution. Ferrero-Regis (2008, p.1) states, *"Historically, the image of the fashion designer has been constructed within a heroic and Romantic narrative centred on the concept of designers as artists and hence authors*." The author of the study criticises fashion education as it fails to present design history as a practice and theory – both education and industry continue to divide the two and promotes romanticism in training designers to focus on their own visions as opposed to working as a team. Over time fashion design has evolved into practical and functional pieces driven by standardised processes. Commercial design and consumers drive the industry – *not* designers at haute couture houses. A lack of understanding between the objective and processes of haute couture and commercial design, in Ferrero-Regis's opinion has, *"confused the field in both the understanding of the processes of making, and writing about fashion"* (Ferrero-Regis, 2008, p.4).

Therefore, the virtual technologies needed or utilised for both models will vary accordingly based on the hierarchy of fashion market segmentation. According to Doreinger and Crean (2005), as the product is further up the pyramid, the products become more exclusive, and craft is often a symbol of heritage and brand identity. This suggests a correlation between technology uptake and the attitudes of adoption. Figure 3.3 demonstrates the hierarchy of fashion market segmentation, with 'Couture' and 'Ready-To-Wear' being at the top – which are highly regarded for leading the industry in creativity and innovation regarding art and design. When considering high technology adoption, it can be hypothesised that these segments are less likely to utilise digital tools, as the tradition and craft of garment making utilising hand-sewing is highly regarded *“as a means of creative expression”* (Nayak and Padhye, 2015, p.3). As discussed in *Chapter 2 Literature Review* in section 2.2.2, fast fashion brands depend on high technologies to achieve production objectives of speed and quantity. However, this is not to say luxury cannot benefit from digital technologies to support the design and production techniques.

Figure 3.3 The Textile and Fashion Industry: Areas of Activity.
Cited Doreinger and Crean, (2005) p.4.

The evolution of garment manufacturing and the industry has led to complex and sophisticated business strategies. It is acknowledged that the ‘Fast Fashion

Revolution' led to great innovation and the availability of fashion for the masses. However, it is argued that the business model compromises not only the individuality, quality, and skill, but removes the 'craft' based on the general literature discussed at the beginning of this chapter. For example,

- Removes materials and craft practice out of its environment with global procurement and outsourcing.
- Fast fashion imitates or 'knocks off' high fashion or the authentic craft product.
- Lower price points sacrifice quality of materials.
- Skills and operations are optimised to achieve the most affordable and best fit garments for as many customers as possible.

Therefore, one must consider the role of 'fashion' designers varies. For example, a commercial designer and haute couturier will have different design objectives.

As ideals of romanticism are still evident within contemporary fashion practice, this suggests a reason for fear of new technologies as it challenges the designer's identity to disrupt the reality of their practice. However, this suggests romanticising concepts of authenticity and craft, underscoring the need for fashion education to be evaluated to align with industry practice. The relevance of themes of craft and authenticity in the context of commercial design is questionable. This in turn questions the relevance of themes of craft and authenticity, as an opposition for the uptake of virtual technologies. One might argue rejecting virtual technologies attempts to restrict opportunities for new avenues of craft and authenticity to reflect and compliment the contemporary world.

3.6 Summary of Chapter three

In this chapter, the general literature on themes of craft and authenticity is explored, defining these terms within the context of the fashion industry. These concepts are frequently discussed in relation to 3D design software for garment product development. Moreover, this chapter also defined 'technology' and the ambiguous meaning. For the purpose of this study, 'high technology' refers specifically to technology involved in the virtualisation process.

One proposed benefit of this technology is its potential to enhance authenticity and craft in a designer's process. However, these themes are also cited as reasons for resistance to adopting such technology, a trend historically prevalent in the industry. Parallels can be drawn from the Arts and Crafts Movement to contemporary debates surrounding industrialisation with Industry 4.0. The tension between craft and technology persists, with high technologies and virtual platforms challenging traditional fashion design ideals. The significance of craft and authenticity is further complicated by differing objectives across market segments (e.g. haute couture vs commercial design). The hypothesis proposes a correlation between willingness to adopt or reject technology and market segment. Similar to the Arts and Crafts Movement, commercial design challenges themes of craft and authenticity. One could argue the romanticism of designers leading the industry is misinterpretation of reality, as consumers drive what is produced. The empirical research will delve into themes of craft and authenticity to provide deeper insight into the attitudes of designers – who are most likely to be directly impacted by virtualisation.

Chapter 4 – Methodology

4.0 Introduction to Chapter 4

This chapter on methodology comprises of two broad aspects: (i) the theoretical orientation and justification, and (ii) an account of how the research was undertaken, including the data collection methods and types of data. The chapter draws on key texts on methodology for social scientists, such as Creswell (2009), and for the specific field of ethnography (Atkinson and Hammersley, 2007).

The first part of this chapter discusses the research philosophy and the rationale of adopting an interpretivist stance and ethnographic method that guided this PhD study. The research approach, objectives, and data analysis are included in Section 4.2 Ethnographic framework. The second part of this chapter details the practical implementation of the data collection and provides an overview of each chosen method. Overall, this chapter provides a comprehensive overview of the methodological framework to ensure a clear understanding of how the research was designed and conducted.

4.1 Research philosophy

For this study, adopting an interpretivist stance and utilising an ethnographic approach as the primary research method is the most suitable choice. Unlike other product and creative industries, the fashion industry remains traditional within its product development process. As discussed in the literature review, fashion practitioners have a history of resistance towards new technologies. The uptake of virtual technologies, particularly 3D design software, is once again disrupting the fashion industry, which is currently at the start of the technology adoption curve. According to Muratovski (2022, pp.101-102),

> *Ethnography lies at the core of human-centred design (p.80)" and that "by studying the social and the cultural contexts in which we are working, we can create better everyday experiences for the people for whom we design.*

With a flood of new technologies entering the market, it is easy to feel overwhelmed. Moreover, a lack of understanding of virtualisation and the technologies can lead to unrealistic expectations, resulting in missed opportunities. However, a more objective approach is to remain open and explore the actual reality of what this means for the industry, considering both positive and negative impact. To better understand this transition, this PhD study highlights the humanistic aspects within the conversation of technology and virtualisation, aiming to understand the motives, challenges, and attitudes of a traditional industry as it adapts to virtual practices.

4.2 Ethnography framework

In ethnography, designing the initial research framework is challenging due its exploratory nature, including decisions on where to start and whom or what to observe. However, as the investigation progresses, the researcher's initial interest and questions are refined and clarified (Atkinson and Hammersley, 2007).

This study began with exploring the literature to identify common themes related to the research question. Coinciding with the start of the COVID-19 pandemic in Spring 2020, the doctoral study observed a significant acceleration in the uptake of digital technologies, such as 3D design software, which enabled virtualisation within product development. Therefore, attitudes towards digital technology were shaped during this time.

This study undertook empirical research, utilising both quantitative and qualitative methods. Quantitative research focuses on quantifying data collection and analysis, while qualitative research gathers primary data and interprets the findings to deepen understanding of a topic. The thesis adopts a mixed methods approach to address the research objectives. Initially, data collection is mostly unstructured, and generates insights through analysis (Atkinson and Hammersley, 2007). Using multiple methods informed each method for a more in-depth study, and to establish reliable and credible research through cross-referencing (Muratovski, 2022). The chosen methods includes:

- Survey
- Interviews
- Case studies (methods include interviews, focus groups and observation)

These methods will be examined in greater detail, and the design of each will be discussed later in this chapter.

All data collected and processed during the doctoral research was handled in compliance with the General Data Protection Regulation (GDPR) as it applies in the UK, tailored by the Data Protection Act 2018. Video and audio data files were kept on password-protected computer systems to which only the researcher involved in this research had access. Video and audio recordings from this research will not be shared. Data was pseudonymised and stored securely on a password secured hard drive. For the protection of the participants and myself as the researcher, informed consent for research (Surveys, interviews, observation) were obtained from potential participants.

4.2.1 Research approach and rationale

The limited academic literature on the adoption and use of digital technologies in apparel / garment product development at the start of the doctoral research project highlighted a gap between academic discourse and industry practices. Moreover, recognising the prevalent use of marketing-driven jargon in industry literature, the survey method was initially selected to assess the actual adoption of digital technologies within the product development process. The survey aimed to gather descriptive data in relation to the research objectives and served as a networking tool to recruit participants for the next stage of the methodology.

Following the survey, the interview method was chosen to explore a more in-depth analysis of a participant's answers in which the survey was unable to provide. The semi-structured interviews explored the views and experience regarding 'what works', what might be improved, and why. For details of the interview format, see Appendix D Interview Question Route.

In ethnography, the researcher usually participates within their environment in 'everyday contexts' to observe what is occurring within the space, asking questions, and active listening. The case study method was chosen as it has many advantages such as allowing flexibility for deductive or inductive reasoning – meaning to be able to test or develop theory. The case study method allowed the researcher to observe the phenomenon within a real-world context to understand the practicalities of the PhD research question and contributed to a more comprehensive analysis.

For this study, three case studies were carried out for the purpose of cross examination of how companies are utilising digital tools to support virtualisation. The case studies contribute to filling the gap in the literature on how organisations are utilising the technology within an environment (as discussed in Hoque et al., 2020). The three companies selected made for interesting subjects to observe as they represent three levels of adoption of digital technologies within business models and sectors. Each chosen method will be discussed in more depth in their respective sections later in this chapter.

4.2.2 Research objectives

This doctoral research addresses the question:

> *How is virtualisation of the product development process impacting the fashion industry?*

To address the research question, the following objectives have been identified:

Objective 1: To understand the processes by which companies are undertaking virtualisation and the technologies enabling this.

- Literature review
- Survey method
  - Identify the technologies that are enabling virtualisation – in the form of a list and the parts in the process were used.
  - Identify companies (100+) that are identified as using 3D design software (on the websites of 3D software companies, trade press, etc.).
  - Administer a survey to companies about their use of 3D software.
- Interview method
  - Conduct interviews with consultants supporting 3D design software (x15).
  - Conduct interviews with those working for companies using 3D design software (x15).
- Case study method – including non-participant observation, interviews, and focus groups.

- Identify potential case study of fashion design companies and conduct 1–3 case studies using mixed methods.

Objective 2: To understand the impact of virtualisation of the product development process on the fashion industry. Including how virtualisation of design and product development processes has impacted issues relating to the fashion design profession, such as 'craft' and 'authenticity'.

- Literature review
  - Identify from the literature concepts of ‘craft’ and ‘authenticity’
- Interview method
  - Content analyse data from the interviews undertaken in 2 and 3 above.

4.2.3 Data analysis

The data analysis was carried out using a thematic analysis approach. Ethnographic research accumulates a large body of data and demands intense reflection in the data analysis. Atkinson and Hammersley (2007, p.4) states,

> *What is involved here, then, is a significant development of the ordinary modes of making sense of the social world that we all use in our mundane lives, in a manner that is attuned to the specific purposes of producing research knowledge.*

For analysing the data, Muratoviski's three steps were used to structure the data collection (2022, p.99):

1.) **Describe the data:** Comprehensive field notes were taken, and formal conversations were transcribed, considering participants' professional backgrounds, organisations, and cultures to achieve a holistic and thorough understanding of the data.

2.) **Categorise the data:** Each data set were organised into distinct sections, serving as a starting point. Each transcript was carefully analysed to identify response patterns, including similarities and differences, and underlying themes in responses.

3.) **Interpret the data:** Data interpretation used a thematic approach involving review and organisation of each data set into thematic categories. These themes emerged from the data collection process and were contextualised with relevant literature.

The following sections will explore into greater detail on the three selected methods and discuss each design approach. Additionally, the results from each method will be presented in their respective chapters.

4.3 Survey method

This section provides an overview of the survey method – its origins, development and use within the fashion industry – before detailing how the survey method was applied to address the PhD research objectives.

4.3.1 Origins of the survey method

The survey method has evolved since its beginning in 1788 with the first mail survey documented in Scotland (Cowles and Nelson, 2019). At the beginning of the twentieth century, surveys were carried out face-to-face to evaluate working-class conditions in England. With the diffusion of telephones in the 1980s, phone surveys became the most frequently chosen method. However, the 1990s brought a number of challenges, including no call lists and number blocking. The introduction of mobile phones also has affected response rates and limited sample size (Tanner, 2018). Once again, with the rise of the internet age, the process for administering surveys has changed, with online surveys replacing phone surveys.

Uses of survey methods

Using survey methods, social scientists set out to understand in a scientific way attitudes, behaviours, and the relationships among people. According to Punch (2003), surveys have become popular among social scientists for reasons such as:

- To generate understanding and make generalisations about a specific group of people.
- To capture the attitudes and perceptions of a group of people.
- To collect demographic and socio-economic data.

Surveys can be exploratory, descriptive, or explanatory. Although surveys are most commonly descriptive or explanatory.

- **Descriptive** – sometimes called status surveys, descriptive surveys describe a phenomenon, gather facts, and give a glimpse into a given time and place. These surveys answer: what, who, when, how much, how many, how often.
- **Explanatory** – sometimes called analytical surveys, explanatory surveys explore deeper understanding than descriptive surveys to explain “how” and “why”.

Survey results aim to describe and explain a population's attributes, viewpoints, or behaviours, which might be an indicator for future behaviour. While the survey method is typically associated with quantitative research methods, surveys can also be used to collect qualitative data.

The advancement of technology has also allowed researchers to use a ‘mix mode’ survey approach, which is common for data collection (Leeuw, 2005). The internet and access to personal computers have made the process of managing and analysing statistical data easier (Sheard, 2018). Surveys can be conducted in different ways such as the following:

- Telephone surveys
- Postal surveys
- Online surveys
- Personal interview-based surveys
- Mixed-mode surveys

While the telephone has to some extent replaced face-to face surveys, online surveys are currently the most commonly used to administer a Survey.

Advantages and limitations of survey methods

Surveys have become a popular method for capturing attitudes, beliefs, and opinions (Phillips and Stawarski 2008), as well as collecting information for a variety of reasons. According to Loomis and Paterson (2018), advantages of the survey method often include the following:

- Cost effective
- Can reach a large group of participants
- A quick way of gathering data

- Easy to administer

There are, however, some limitations of the survey method. For example, surveys are limited in the level of detail or reasoning behind a choice compared to other methods – such as interviews which allow for a more in-depth conversation (Phillips and Stawarski, 2008). Despite online surveys being the most commonly used way to administer data, the method still has limitations. For example, some people would prefer not to fill out a survey online. Additionally, access to a computer or lack of knowledge on how to use a computer can be barriers for some groups. As a result, certain groups of people are missed during sampling.

4.3.2 Use of surveys in the fashion industry

Surveys are used to understand and support the fashion industry in a number of ways, such as to improve products, to make business decisions, or gauge consumer perceptions of a firm (Hayes, 2008; Quinn et al., 2007). Additionally, firms such as trend forecasters create consumer surveys about product preferences (DuBreuil and Lu, 2020). Regarding the adoption of technology in the fashion industry, the following are sources provide reliable surveys,

- Business of Fashion (BOF)
- Women's Wear Daily (WWD)
- McKinsey and Company
- CB insights
- Mintel
- WGSN Trend Forecasting
- Kalypso Rockwell Automation
- WEAVE Consultancy
- The Interline

4.3.3 Survey design

In this study, a survey was undertaken to collect descriptive data in relation to the research objectives. Survey questions were developed from a combination of themes within the literature and topics covered in relevant industry conferences and webinars.

The survey is divided into four sections: 1) Virtualisation 2) 3D Design Technologies/ 3D Prototyping 3) Impact of the COVID-19 pandemic 4) About the Participant. Participants were asked to rate each question using the Likert scale, the most widely used scale in social sciences to capture attitudes in a scientific way (Joshi et al., 2015). See Appendix B: Survey question route. JISC Online Survey (Bristol Online Survey) was the identified method to create and administer the survey. The survey for this PhD study was closed on 13 August 2021. To review the full survey results, see Appendix C: Results of Survey.

4.3.4 Survey framework

The PhD survey sample of participants are made up a wide range of fashion industry professionals, and can be grouped into three main groups:

- **Garment industry professionals**: includes company executives; directors; consultants to the garment industry; fashion designers; technical designers; 3D artists; print designers; and textile designers.
- **Retail professionals:** includes fashion buyers and merchandisers.
- **Technology professionals:** includes professionals enabling virtualisation such as: technology developers and vendors; software developers and vendors; and technology research and development professionals.

Survey participants were approached through professional network platform LinkedIn, industry bodies, personal industry connections, and alumni groups. Key industry bodies and associations have been identified from the academic and trade literatures – including British Fashion Council and Fashion Designers of America. These have been approached to disseminate invitations to their members to participate in the survey.

Following the end of the online survey, respondents were asked if they would be willing to participate in a follow-up interview, and if so, will be asked to provide their contact details (email address). Out of the 35 survey respondents, 20 agreed to being interviewed. Survey participants indicating their willingness to participate in interviews / focus groups were contacted via email. Contacts gained through previous networking (e.g. attendance at events; online communications; etc.) or who have contacted the researcher due to their interest in the research area, were approached by email to participate in the research. To recruit other participants, trade publications and industry connections will be asked to share a project information sheet with their network as stated in the ethical approval application.

4.4 Semi-structured interviews

The interview method was the second chosen to carry out a more in-depth discussion to better understand the use and adoption of digital technologies within the fashion industry.

Interviews are often the basic method in data collecting, especially within social sciences (Williamson, 2018; Gabrium, 2012). The interview process allows for a deeper discussion and understanding of quantitative data. Moreover, interviews are not simply a list of questions to be answered (Gabrium, 2012), but must conform to the right interview structure. The actual structure depends on the objectives of the research and what information the researcher is seeking to obtain. Three commonly used types of interviews are: 1) Structured interviews 2) Unstructured interviews 3) Semi-structured interviews:

Structured interviews are similar to a survey in that they consist of a set of questions with, *"little room for deviation from the desired response"* (Phillips and Stawarski, 2008, p. 24). Structured interviews enable a controlled discussion and offer insights that might be otherwise missed during a survey. They are often chosen to capture standardised responses (Williamson, 2018). Additionally, structured interviews allow the researcher to capture a larger sample pool and include those who cannot fill out a survey.

Unstructured interviews consist of a set of general questions that allow the interviewer to question and expand on an answer, and for responses to naturally flow from each response. They are often utilised when studying a new phenomenon where the outcome is unpredictable or to gain knowledge or insight on a subject to structure a semi-structured or structured interview (Williamson, 2018).

Semi-structured interviews combine aspects of structured and unstructured interviews by consisting of both open-ended and closed questions. Similar to unstructured interviews, they enable a deeper exploration and understanding of the explored topic. One advantage of this approach is that it allows for direct quotations from participants to be captured through recording of the interview (Williamson, 2018).

4.4.1 Advantages and limitations of interviews

The interview method offers many advantages, including the opportunity to build rapport with participants and to allow them to ask for further explanation or clarification of the questions, ensuring comprehensive responses. Additionally, the researcher also has more control over the interview process.

There are, however, limitations to the interview method. For example, interviews can be costly and time-consuming. Moreover, conducting interviews requires the skill to remain neutral in tone and opinion to ensure the researcher does not influence the participant's response. Additionally, recruiting participants may be challenging due to concerns about company confidentiality, resulting in reluctance among participants to speak freely for their identity being exposed (Williamson, 2018).

4.4.2 Semi-structured interview framework

The purpose of the semi-structured interviews is to investigate the implementation of virtualisation in traditional business activities and the approaches taken by retailers and manufacturers to address these. Participants will share their views and experience regarding ‘what works’, what might be improved, and why. Similar to the survey, the interview questions were developed from a combination of themes within the literature and topics covered in relevant industry conferences and webinars. In identifying questions, two strategies were adopted:

- **Strategy 1**: Review questions in the survey. Identify questions that need clarification for deeper understanding. Redesign questions to prompt discussions for qualitative data collection.
- **Strategy 2**: Review survey responses and note interesting responses. Formulate questions to follow up based on those responses.

A semi-structured interview was used to provide structure, but also to allow participants to expand on the topics covered. A set of questions and prompts were developed, and open-ended answers were encouraged. Like the survey, the interview questions were developed from a combination of themes within the literature and topics covered in relevant industry conferences and webinars.

The survey method identified three sample groups of fashion professionals, which further investigation and comparison was carried out during the interview process and data analysis. Interestingly, most of the respondents in the survey are in the roles of managers and directors. Therefore, they will most likely not be the ones utilising the technology day-to-day. The survey highlighted a need for more insight from designers about their attitudes towards technology and virtualisation. Semi-structured interviews were conducted with designers (print, fashion, technical, etc) to gain insight in how virtualisation impacts their design process and day-to-day responsibilities. Additional questions were asked regarding authenticity and craft in designers' practices to meet the project objective (refer to Section 4 in Appendix D: Interview Question Route). Discussions were also held with consultants, directors, and managers on how virtualisation would impact designers in terms of craft and authenticity.

Participants were identified and recruited through the survey. Those indicating their willingness to participate in interviews or focus groups were contacted via email. Out of the (x35) survey respondents, (x20) agreed to be interviewed. Moreover, contacts gained through previous networking events or who have directly contacted the researcher due to their interest in the research area, were also contacted by email to participate. To recruit other participants, trade publications and industry connections were asked to share a project information sheet with their network as stated in the ethical approval application.

Participants signalling their willingness to take part in the research were sent the *Project Information Sheet* and the *Informed Consent Form*, which they were asked to complete and return prior to commencement of the interview / focus group. Interviews were conducted in person, and / or online (via Microsoft Teams or Zoom). The researchers took notes during the interview, and the discussion was recorded to assist in writing up accurate notes. Informed consent was obtained before recording.

4.5 Case Studies

Ethnography research studies social phenomena within groups, communities, or organisations. Therefore, being immersed in the natural environment of the phenomena along with the participants is often conducted through fieldwork (Atkinson and Hammersley, 2007), and crucial for this PhD study. Moreover, according to Shanks and Bekmamedova (2018, p.194), case studies are often conducted in the discipline of Information Systems *"...providing understanding of the interactions between information technology (IT)- related innovations and organisational contexts."* Hence making case study research an excellent method for this PhD research study.

Following completion of the interview process, three case studies were conducted. The interview process was also utilised as a strategy to identify potential companies. The researcher carried out case studies to contribute knowledge in this area of limited research in regard to the fashion industry and virtualisation. The case studies aim to describe the phenomenon occurring in the industry and develop theory through inductive analysis of the case study outcomes.

4.5.1 Advantages and limitations of the case study method

Case studies allow for exploration of a contemporary phenomenon within a real-world context involving stakeholders to investigate *'How'* and *'Why'*. They involve a mix of methods that might include interviews, field observation, surveys, and document analysis. Therefore, case studies can be considered both quantitative and qualitative data collection methods.

The case study method has many advantages such as flexibility for deductive or inductive reasoning – meaning to be able to test or develop theory. In addition, case studies are useful when the complexity of a phenomena cannot be examined outside the environment in which it occurs. The implementation of technology is an example of a complex system that needs to be examined *in situ*. This allows for a deeper investigation in an uncontrolled environment and allows the researcher to observe the impact on an organisation and/or the stakeholders (Shanks and Bekmamedova, 2018).

There are also many limitations within the case study method. For example, developing a framework to successfully answer the research question can be difficult. Case study research can be time consuming to conduct and create large data sets to be analysed. Additionally, arranging case studies can be challenging – such as gaining access to an organisation due to issues of confidentiality or convincing organisations to allow participation. Most importantly, ethical consideration must be decided and approved between both the researcher and organisation (Shanks and Bekmamedova, 2018). To convince organisations to participate, research questions will need to demonstrate value and be of interest to the organisation.

4.5.2 Case study framework

For this PhD research study, three case studies were carried out for the purpose of cross examination of how companies are virtualising and utilising digital tools to support virtualisation. The case studies contribute to filling the gap in the literature on how organisations are utilising the technology within an environment (as discussed in Hoque et al., 2020).

To develop the case study framework, multiple factors were considered. Constructs and themes from the literature were reviewed, and investigation of themes emerging from research findings of previous methods were taken into consideration. The case studies set out to address the following three objectives:

Objective 1: The practicalities of implementing virtualisation technologies: This might include: strategy development; technology selection; practical implementation challenges (including continuing professional development; problems / issues; client issues); etc.

Objective 2: The practical reality of virtualisation for the company's design / product development processes: This may include various teams such as inhouse design teams or garment retailers (e.g. applying patternmaking techniques into digital twin models for prototyping, decision making process, presentation to retailers, etc.)

Objective 3: The human / social impact of virtualisation processes: on designers, others involved in the design process and company culture.

Prior to onsite visits, initial planning meetings with managing directors were conducted, and company literature and materials were gathered. The phenomenon to be observed was the PhD research question, and involved observation within companies that utilise virtual enabling technologies. In addition, designers and their working space were observed to meet project objectives to explore concepts of 'craft' and 'authenticity'. Chosen methods to carry out the study include observation, interviews, and focus group. The case studies were conducted at the head offices, and observation of daily business activities was carried out to understand the nature of the business.

The interview process served as a strategy to identify companies and recruit participants for the case studies. Network connections who expressed interest in the PhD research were also formally invited to participate. To overcome the challenge of gaining access, formal documentation of project objectives and nature of the project were provided. In addition, a project information sheet discussing how the research project is relevant and adds value to their organisation was provided. Regarding ethical practice, ensuring the organisation of privacy will be stated in an informed consent document for the organisation.

4.5.3 Selection of companies

The three selected companies serve as interesting subjects for observation, representing three levels of adoption of digital technologies within different business models. For this study, the companies are mapped onto Everett Rogers' 1995 Diffusion of Innovations (Rogers, 1995). The researcher has classified each company as follows.

1. **Company 1 – Early Adopters:** defined as having an interest in technology and seeking technology to create solutions. Company 1 fits this description as one of the leading organisations in their sector for adopting and successfully implementing 3D design technologies within their workflow prior to the COVID-19 pandemic.
2. **Company 2 – Innovators:** characterised by a strong interest and willingness to experiment and invest in technology, Company 2’s inner workings and emphasis on virtual technology align with this description. The company

identifies as a *‘digi–physical’* micro factory and was established as a lab for experimenting with new digital technologies to drive innovation in fashion business and product development.

3. **Company 3 – Late Majority:** defined as the late adopters of the majority to adopt technology, Company 3 is placed in the late majority category in the adoption of virtual technologies within product development. However, Company 3 can be considered an innovator in adopting and investing in manufacturing technologies.

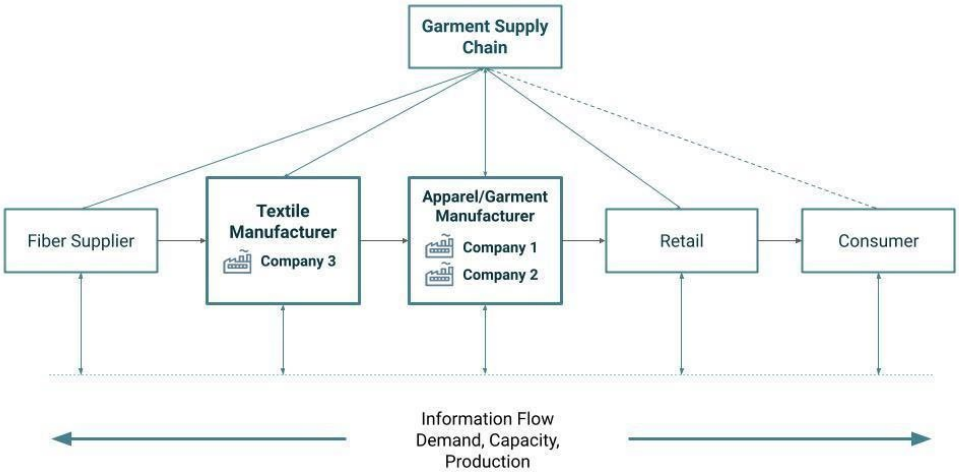


Figure 4.1 The Textile and Fashion Industry: Areas of Activity
Adapted from Coughlin, Rubin, and Darga (2001, p.81).

Each Company has its own set of needs and challenges regarding their specialisation of product categories, business models, and sectors. This in turn shapes their views, attitudes, and investment in the level of adoption of technologies related to virtual technologies within product development to suit their organisations. Company 1 and Company 2 are Apparel / Garment Manufacturers, and Company 3 is a Textile Manufacturer (See above Figure 4.1). How the three selected companies are relevant to this PhD thesis and why they were chosen are discussed as follows:

Case Study 1– Company 1

Company 1 is a suitable case study to explore the PhD research question, aiming to understand the practicalities of virtualising the product development process from the perspective of the garment/apparel manufacturer. The survey and interview findings reveal that only a few organisations have integrated 3D design technology into their workflows. Nevertheless, Company 1 has effectively incorporated 3D design software within their product development process, evidencing measurable outcomes. The case study demonstrates how virtual technologies are utilised within the product development processes and explores the barriers / challenges Company 1 overcame to reach desired outcomes. Moreover, the company has identified production to be the next area of focus to understand what relevant virtual solutions to incorporate and assess the feasibility to achieve 'end-to-end' digital transformation.

For Case Study 1, individual interview participants include: CEO, CEO and Founder, Design Team Lead, Sales Team, Buying Team, System Architect, Business Developer, and Brand Director. See Appendix F for a list of roles and main responsibilities. Both the Sales Team and Design Teams were chosen as focus groups. A meeting with the two members from the patternmaking/ technical team was conducted via video conferencing as the team is based in Lithuania. In total, conversations were carried out with 13 employees representing a variety of teams.

Case Study 2– Company 2

Company 2 was selected for the case study research to explore the inner workings of an organisation not undergoing digital transformation but established on digital principles. The company envisions a digital factory that "*trail-blaze the future of garment design and production towards financial, social and ecological sustainability",* and to enable garment production through *"innovative usage of cutting technologies"* (Company 2 Website, 2022). Operating as a "*digi-physical micro factory",* Company 2, leverages digital technologies to experiment with new business models, such as an open-source fashion system. A *"micro-factory"* facilitates smaller batches of production and offers bespoke services.

The advantages and disadvantages in the adoption and use of digital technologies share commonalities but will vary between the other two case studies companies. This in turn makes for an intriguing discussion and case to explore. Moreover, Company 2 provides practical insights into the current limitations and possibilities of virtual technologies, laying the groundwork for theories such as Industry 4.0 and proposing potential solutions to some of the fashion industry's pressing issues.

For case study 2, individual interview participants include: Founder and Creative Director, Founder and Business Director, Lead Garment Technician, Digital Fabric Intern, and Purchasing Coordinator. The main office held both the design studio and production facilities. The company consists of the team made of fashion designers, machinist, patternmakers, and digital designers, (Company Website, 2022). Company 2 is a small company, which started with five employees and has recently expanded to eight employees. The production team was not interviewed as there was a language barrier and did not work with digital technologies. In total, conversations are carried out with 5 employees. See Appendix G for a list of roles and main responsibilities.

Case Study 3– Company 3

As brands and retailers adopt 3D design technologies, the demands and expectations placed on their suppliers and mills to embrace virtual technologies will inevitably impact these organisations. While the PhD research study primarily focuses on the garment / apparel sector of the industry, it is important to consider the impact of virtualising product development on suppliers and mills. From the interview findings and the first two case studies, some participants emphasise the importance of digital fabric and the digitisation process. The foundation of garment development is the materials and hard components which make up garments. Therefore, Company 3, as a denim mill exploring fabric digitalisation, offers a different perspective compared to the first two companies. Hence, it makes a suitable case study to further explore the PhD research question and gain insight into the upstream effects of virtualization in the value chain.

For case study 3, individuals interviewed involved in the case study includes: sales, product developers, account managers, merchandising, directors, President, and vice price presidents (Company Internal Organisation Chart, 2023). In total, conversations were carried out with 18 employees. See Appendix H for a list of roles and main responsibilities.

4.6 Summary of chapter four

This chapter outlines the methodology of the PhD research study. This study adopts an interpretivist stance, utilising ethnography as the primary method to explore technology's impact within the product development process. Similarly, the method for collecting data through surveys has been influenced by technology – particularly with the computer (Kalton, 2019). Consequently, this has transformed the way in which surveys are administered and analysed.

The thesis adopts three methods: survey; interviews; and case studies, each informing and complementing the others while serving as a recruitment tool. The design of each method was guided by both academic and industry literature. The survey was the initial starting point of the data collection and aimed to gather descriptive data aligned with research objectives. Semi-structured interviews were chosen for their structure while allowing the participants to expand on their responses. Additionally, this method allowed for a more in-depth analysis of a participant’s answers in which the survey was unable to provide. The case study method further enriched the PhD study by offering real-world observations and insights into the practical implications of virtualisation within fashion product development. The following chapters will present the findings from each method.

Chapter 5 Survey Report: results and discussion

5.0 Introduction to Chapter 5

This chapter presents a discussion of the findings of the conducted survey aimed at understanding the effects of virtualisation on the product development process in the fashion and apparel/garment Industry[2]. The survey served as the initial research method to better understand how the industry is implementing virtualisation[3]. The chapter begins by identifying respondent groups and interesting dynamics to explore. Beginning with Section 5.2, the primary themes that emerged during the data analysis will be discussed.

5.1 Roles of respondents

The survey identified six groups of respondents to hypothesise the reasons and motives behind the quantitative data. This section examines the roles and sectors of the respondents and acknowledges perspectives from:

- Consultants
- Footwear, wearable tech, accessories / hardware
- Designers: fashion, technical, print, and textile
- Business developers, research, and development
- Higher education
- Technology software vendors

The following sections provide further details about specific respondent groups and identify interesting dynamics for further investigation in the next research method.

5.1.1 External vs internal respondents

As leaders in the industry, the views of (x3) consultants, (x8) managers, and (x13) directors were important to consider. Initially, the responses of consultants (external view) were to be compared to the managers and directors (internal view) as both groups have different responsibilities and objectives to meet. For example,

---

[2] Full survey results are provided in Appendix C.

[3] The survey design and layout are provided in Appendix B.

managers and directors might be more likely to make decisions from a commercial standpoint, which might lead to a more positive view of their investments. Whereas consultants might have a more critical attitude and approach as a result of gaining insight into multiple companies. Although a direct comparison cannot be drawn from the quantitative data collected, it is important to consider the motives behind each group's responses when analysing the data. This dynamic will be explored further in the personal interviews.

5.1.2 Footwear, wearable tech, accessories/ hardware respondents

An interesting group to emerge included (x3) respondents who work in (x1) footwear, (x1) wearable tech, and (x1) accessories / hardware. This group primarily develops hard goods – solid or rigid ideas – requiring different technical skills and processes compared to the development of garments, which are soft and pliable. For example, developing footwear requires a different process and modelling software. At Respondent SR03’s company, 3D prototyping technology is used for developing accessories and the ‘hard accessories’ of a garment– such as buckles and buttons. Although this group's responses pertain to hard goods, their insights are not dismissed from this study, as they might be applicable to the apparel / garment sector due to their extensive experience with 3D design technology.

These participants exhibit highly positive attitudes. For example, Respondent CS07, who works in wearable tech apparel, comments, *“...On the hardware side, 3D CAD systems are the standard. It's exciting to have that same capability on the apparel side.”* The established digital infrastructure in these product sectors may contribute to their positive outlook toward virtual technology. Leading athletic footwear brands often value innovation, which is evident in their brand identity and organisational culture. These athletic companies also create apparel / garment product lines; however, the styles are typically less complex and require minor changes compared to fashion-focused companies.

5.1.3 Designers: fashion, technical, and textile

Furthermore, respondents in the role of designers are important to consider, as new digital technologies directly impact their workflow and require upskilling. This may lead to negative views towards technology due to the pressure of learning new skills while managing daily responsibilities and workloads. Managers and directors may lack understanding of the practicality aspects of the work and underestimate the time and supported needed. For example, while managers and directors might be enthusiastic about implementing new technology, they may lack an understanding of the design process (Lee and Jordan, 2021).

There are (x8) respondents in total in this group: (x3) Fashion designers, (x4) Technical designers, and (x1) Textile designers. While a direct comparison from the quantitative data collected is not possible, these issues will be explored in more depth during the personal interviews.

5.1.4 Business developers, research and development, higher education

From the survey results, other groups emerged such as: (x2) Business developers, (x4) Research and development, and (x4) Higher education. Similar to the dynamic between managers and directors versus consultants, these groups are interesting to consider as the reasonings and objectives for their research will vary.

5.1.5 Technology software vendors and 3D Digital Product Creation (DPC)

Technology continues to evolve, and software vendors are in the business of disruption. This group provides valuable insight for this study, as they understand the technical aspect of integration and compatibility of new digital technologies within systems. (x2) respondents participated in this survey. Interestingly Respondent SR019 listed working in the sector of *‘3D Digital Product Creation’* (DPC). According to Riordan and Yester (2019, p.1), digital product creation is an end-to-end product lifecycle practice of, “*... designing, prototyping, and verifying products in a virtual and collaborative environment.”* This sector and those working in this role will be investigated further.

5.2 Virtualisation and Digital Transformation

This section analyses the survey respondents’ current attitudes towards virtualisation and digital transformation. The majority of respondents hold a positive view, with (x13) strongly agreeing and (x9) agreeing that virtualisation is a worthwhile investment. However, (x2) respondents strongly disagree, and one neither agrees nor disagrees. This section will examine:

- Attitudes Towards virtualisation and digitalisation
- Misuse and lack of understanding of virtualisation

For this study, the term 'virtualisation' is defined as the process of creating a virtual (i.e. computer-based) model of a physical object. This is related to 'digitisation', which is the conversion of text, images or sound into a digital form that can be processed by a computer and support daily tasks. The term 'digital transformation' is defined as the integration of digital technologies within all areas of a business, such as new product or service development, production, marketing, and sales. This may include the use of technologies such as 3D modelling and virtual reality.

5.2.1 Attitudes Towards Virtualisation and Digitalisation

Overall, the attitudes towards virtualisation and digitalisation for the fashion and apparel/garment industry are highly positive, with most respondents expressing strong agreement. Nevertheless, in response to *(Q2) – Is Virtualisation a worthwhile investment for the fashion industry* – (x3) respondents strongly disagreed. See Figure 5.1.

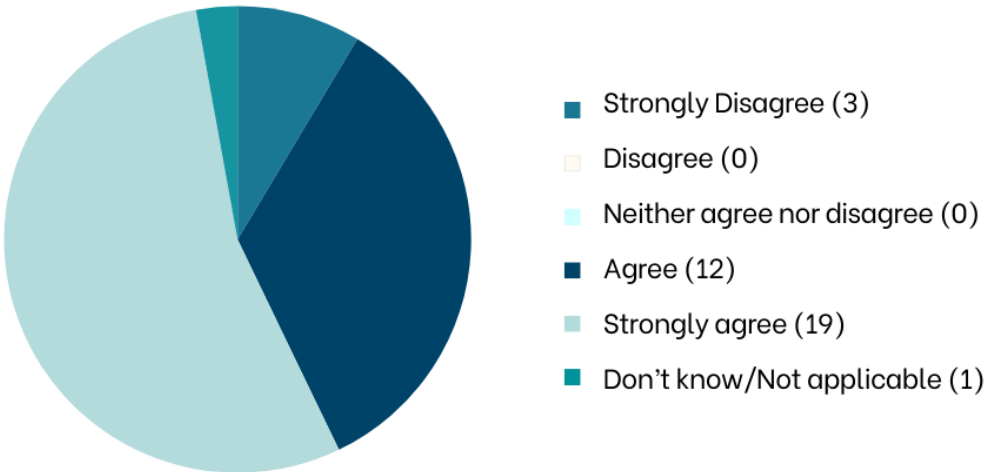


Figure 5.1 Q2 Response– Virtualisation a worthwhile investment

The responses of the (3) respondents were examined to explore the reasons behind their strong feelings. One explanation is that Respondent SR018 and SR09's selected manufacturers who were unwilling to implement new technologies. Connectivity is crucial for realising the full benefits of virtualisation. However, due to the siloed nature of the fashion and apparel/garment industry, communication and information flow are often restricted. Furthermore, the industry's inadequate digital infrastructure compared to other product sectors could also be a significant barrier. Further qualitative research is needed to support this hypothesis.

5.2.2 Misuse and lack of understanding of virtualisation

Despite the positive attitudes towards virtualisation and digital transformation, many respondents are sceptical of the industry's current utilisation of 3D design technologies and the framework required for optimisation. Respondent SR01 comments, "*The 3D tech has been in development for nearly 20 years but has yet to achieve any critical mass. Everybody's talking 3D, but very few are doing it – or at least doing it right."* The respondent views the current 3D design software workflow as a *"flaw in strategy."* Respondent SR01 explains, "*It follows the analogue practice of having designers and technical designers, which 3D tech makes obsolete."*

In addition, both Respondent SR01 and SR034 comment on the industry's focus on *'3D visualisation'* and the *'presentation'* for the purpose of marketing, rather than prioritising the implementation of 3D design software in product development and data management. Regarding digital twins and factory simulation, Respondent SR01 further argues that these concepts are mostly found in marketing materials rather than being effectively applied to support manufacturing. Respondent SR01 also highlights that 3D virtual garment files are not utilised throughout the supply chain, and states,

> *No one is implementing digitisation in the apparel industry like it is executed in other industries like automotive, aeronautics, and food & beverage… Virtualisation is way over-hyped in the industry BUT should be developed to integrate the fragmented supply chain.*

Furthermore, Respondent SR01 suggests one main problem is that fabrics– *'the building blocks of a garment*– are not digitised for manufacturing.

5.3 Issues Experienced Incorporating 3D Prototyping Software

Respondents were asked, *Q13. What issues their company has experienced while incorporating 3D prototyping software within their company's existing IT system?* Most issues raised were related to IT, such as the inability to support 3D digital prototypes within PLM software, leading to some participants to search for a new system (See Figure 5.2).

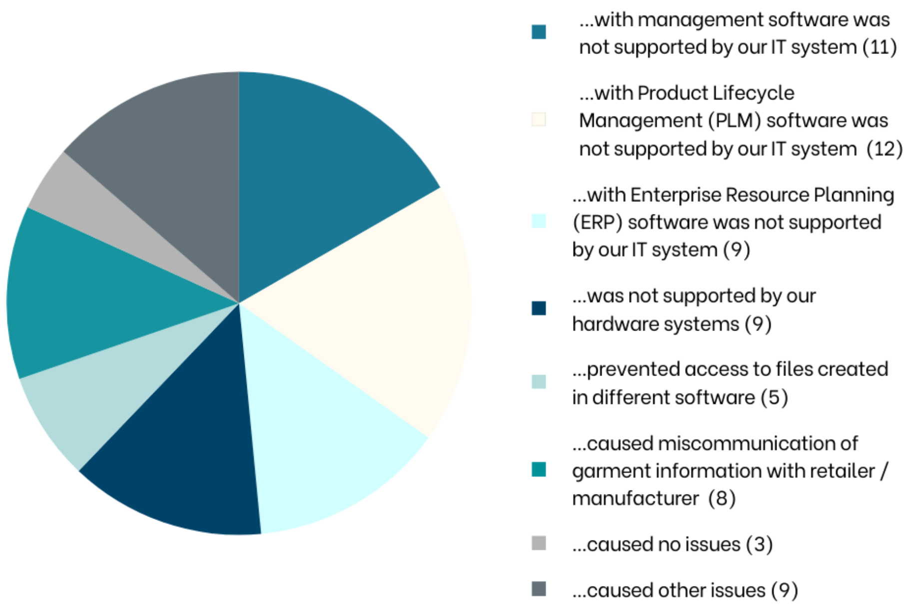


Figure 5.2 Q13 Responses – Issues Incorporating 3D Prototyping Software

Without the appropriate hardware systems some respondents selected *'large files are not supported'*. Moreover, other issues such as overheating computers / laptops and the lack of interoperability of file types across applications were raised. Respondent SR019 suggests that a significant issue lies in the lack of understanding of IT requirements necessary to support systems that require high computer processing units (CPU). Respondent SR019 comments:

> *There's also a big misunderstanding of the requirements to scale the use of 3D. Things like Digital Asset Management (DAM) are fully misunderstood by the industry as are the requirements of things like rendering in high volume.*

Additionally, 'industry infrastructure' and 'organisational culture' are highlighted factors respondents faced while integrating 3D prototyping technology. These factors are addressed in the following sections.

5.3.1 Industry infrastructure and lack of understanding

Respondents highlight the industry's lack of digital foundation and the need for the industry to be redesigned, as articulated by Respondent SR033 who calls for "*a systems architect!*" In response to *Q2.* '*How worthwhile is virtualisation*', Respondent

SR010 suggests that virtualisation will require new processes and training, given that garment product development remains traditionally analogue. This shift would require designers to apply their knowledge of physical product evaluation within a virtual environment. This could result in a *“considerable”* number of issues. Respondent SR010 comments,

> *This might be easier for those with years of real product evaluation experience, but the heuristic nature of product knowledge and practice creates a barrier to the logical linear processing approach of computing which underpins the adoption of virtualisation.*

Although Respondent 3555 commented on having a positive experience in productivity through adopting 3D prototyping; however, the respondent noticed a decrease in outcomes. Respondent 3555 comments:

> *Manual workload showed an increase due to interoperability of files and systems; however, there was a decrease in the amount of styles handled by developers compared to working with 2D styles.*

Additionally, the industry's lack of pipelines for 3D prototyping is raised. Respondent SR015 responds, *“It is just painfully slow to integrate the software to make a holistic solution.”*

5.3.2 Organisational culture and social challenges

Other issues of implementing 3D prototyping software raised are related to the organisational culture or social challenges. For example, Respondent 9328 mentions the unwillingness of staff members or other stakeholders to accept a new way of working due to the complexity of supply chain transformation. Respondent SR014 states, *“It’s hard to train up vendors/factories to meet company virtual standards in a short period. Vendors / factories and staff are not willing to do business transformation.*” The responses are mixed regarding their manufacturers' general willingness to implement new technologies. Further investigation is needed to understand the responses (See Figure 5.3).

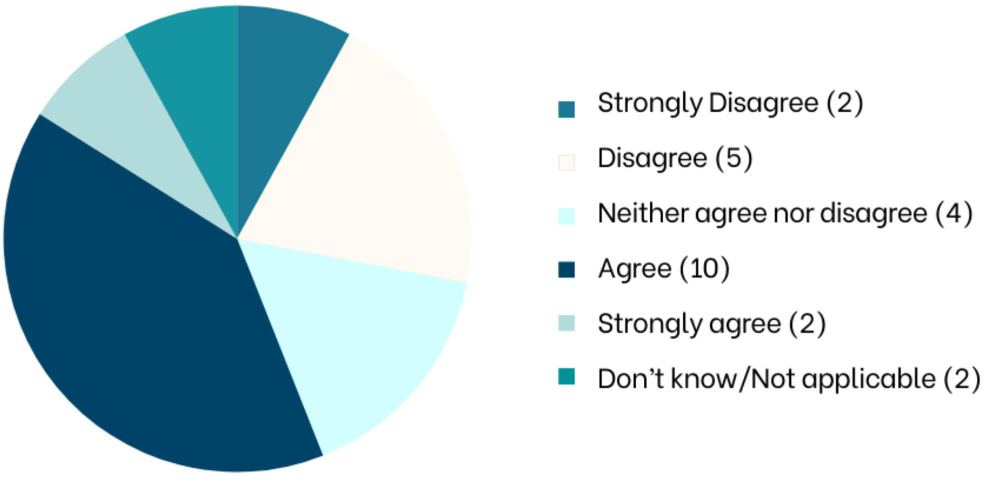


Figure 5.3 Q11 Responses– Manufacturer's Willingness to Integrate Technologies

The respondents were also asked to consider if their retailers are willing to implement new technologies. Interestingly, most of the respondents agree; however, the next most selected response was neither agree nor disagree (See Figure 5.4).

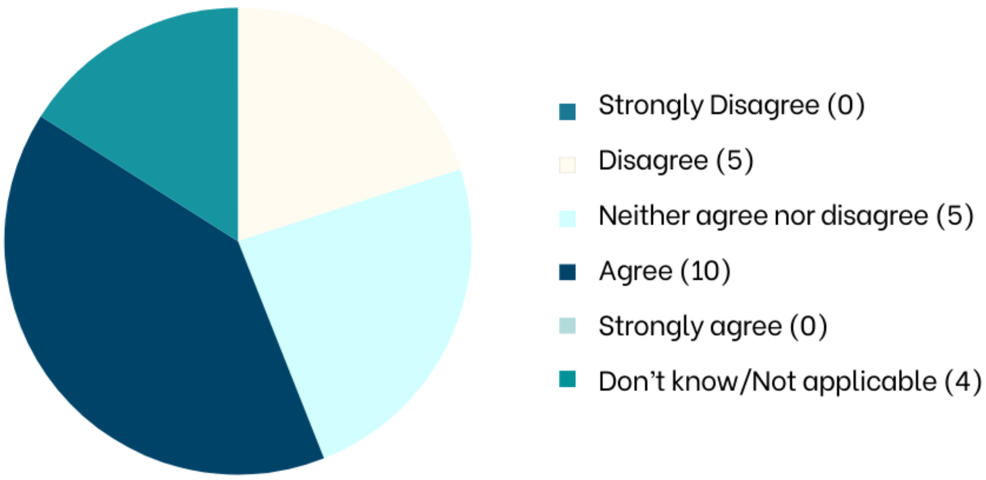


Figure 5.4 Q12 Responses– Retailer's Willingness to Integrate Technologies

5.4 Use of 3D design and 3D prototyping technologies during product development

This section compares responses of adopters of 3D design and prototyping technologies and their use of these technologies during the product development process. Figure 5.5 was used during the survey to ask respondents where along the

Fashion Product Development process they use 3D design technologies and 3D prototyping technologies.

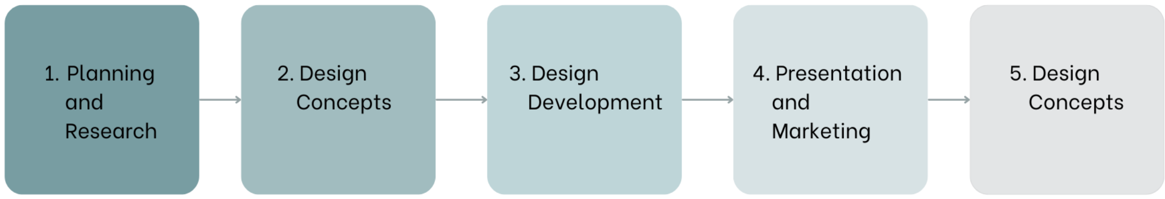


Figure 5.5 The Five Stages of the Fashion Product Development Process *(Adapted from Senanayake, 2015).*

5.4.1 3D Design technology

For this study, 3D design technology is defined as the creation of computer-based three-dimensional models of design proposals to support decision-making around production and other business processes. Out of (x35) respondents, (x28) have been utilising 3D design technology for between 1 and 5 years (Figure 5.6). Overall, the respondents who use 3D design technologies are positive towards virtualisation, which underscores the rationale for investing in these technologies.

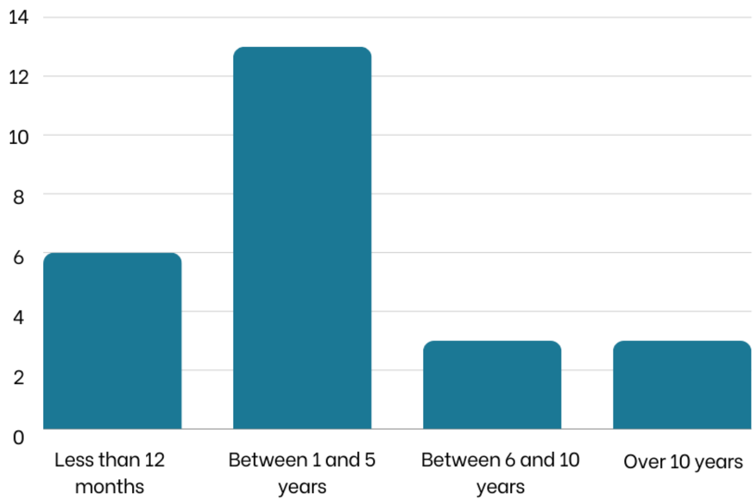


Figure 5.6 Duration of 3D prototyping technology usage

The stages of the product development process in which respondents utilise 3D design technology are Stage 2. Design Concepts, Stage 3. Design Development, and Stage 4. Presentation and Marketing. Only Respondent SR018 selected utilising

3D design technology in all five stages. The stages in which 3D design technology is used by the respondents are in Stage 2 and Stage 3 (See Figure 5.7).

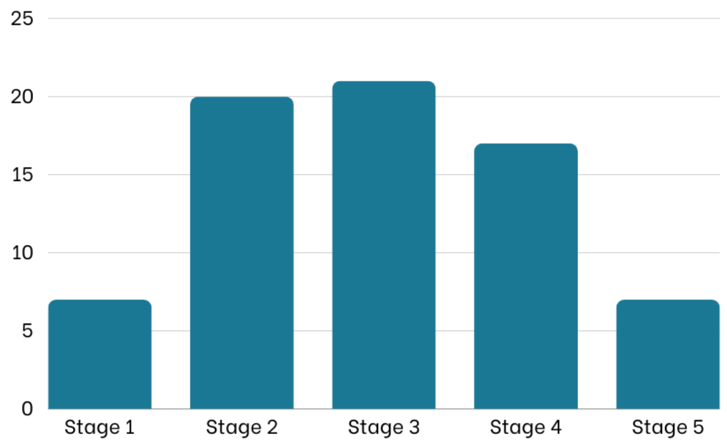


Figure 5.7 Use of *3D Design Technolog*y in the Product Development Process

5.4.2 3D Prototyping technology

For this study, 3D prototyping technology is defined as the use of an interactive digital model of a garment to allow for rapid design changes without the need to create physical prototypes or samples. Out of the (x35) respondents, (x25) respondents are utilising 3D prototyping. Most respondents (x22) I are using 3D prototyping technologies in Stage 3.) Design Development (Figure 5.8). This data supports the responses regarding the use of the 3D digital prototype throughout the supply chain.

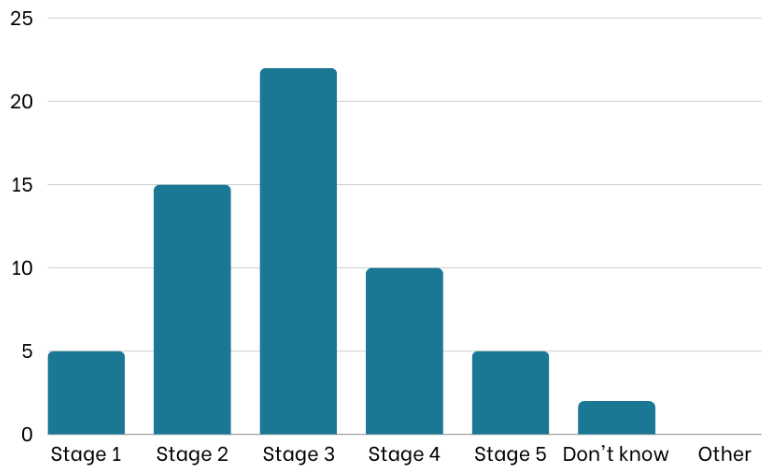


Figure 5.8 The Use of 3D *Prototyping* Technology in the Product Development Process

Most respondents felt positive towards extending their use of 3D design prototyping to other stages of the product development process with (x7) respondents strongly agreeing and (x8) respondents agreeing; however, (x2) respondents strongly disagree.

5.5 Product Management Software

The literature review identified Product Lifecycle Management (PLM) software as a crucial tool for supporting other digital technologies in enabling a virtualised system. This section examines the responses on PLM and ERP software. PLM software encompasses tools that facilitate planning, development, and production activities throughout a product's lifecycle. ERP software manages resources and enhances business development activities. Based on the responses to *Q16. What software is used to manage their company's product lifecycle / product development process?,* most respondents utilise a combination of software (See Figure 5.9).

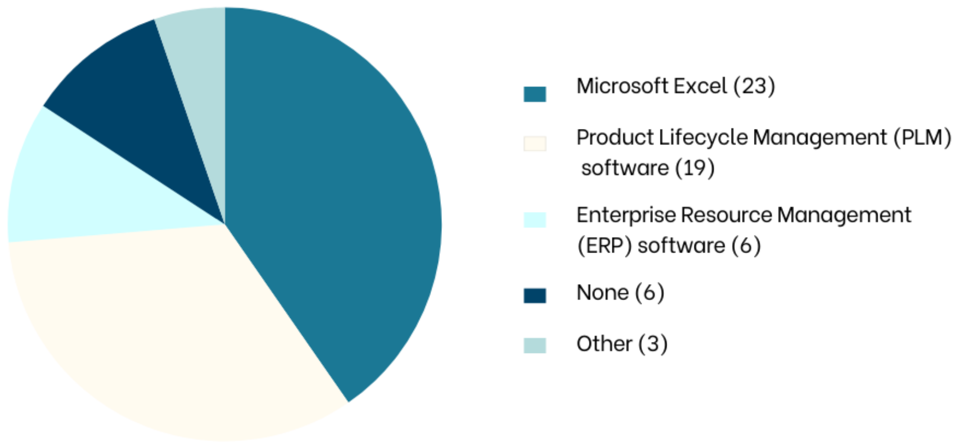


Figure 5.9 Product Management Software

Most respondents (x23) indicated using Microsoft Excel, while (x19) respondents reported using PLM software. Additionally, (x10) respondents rely solely on Microsoft Excel to manage their product development process, and (x3) only use PLM software. Interestingly, (x6) respondents stated they do not use any product management software. Respondent SR033 mentioned their company is actively seeking a PLM solution. Respondents using "Other" software are leveraging platforms that integrate multiple management tools in one platform (See Appendix C

Table 5.1). Further investigation is required to understand how the ‘other’ digital solutions fit within the product development process.

PLM software presents its own set of challenges and processes, underscoring the complexity of managing multiple technologies and processes within a system that decision-makers must consider updating. When respondents were asked *Q16. Is Product Lifecycle Management (PLM) software a worthwhile investment?,* attitudes varied, yet overall, (x14) respondents strongly agreed that PLM is worthwhile, contrasting with responses towards ERP software (Figure 5.10).

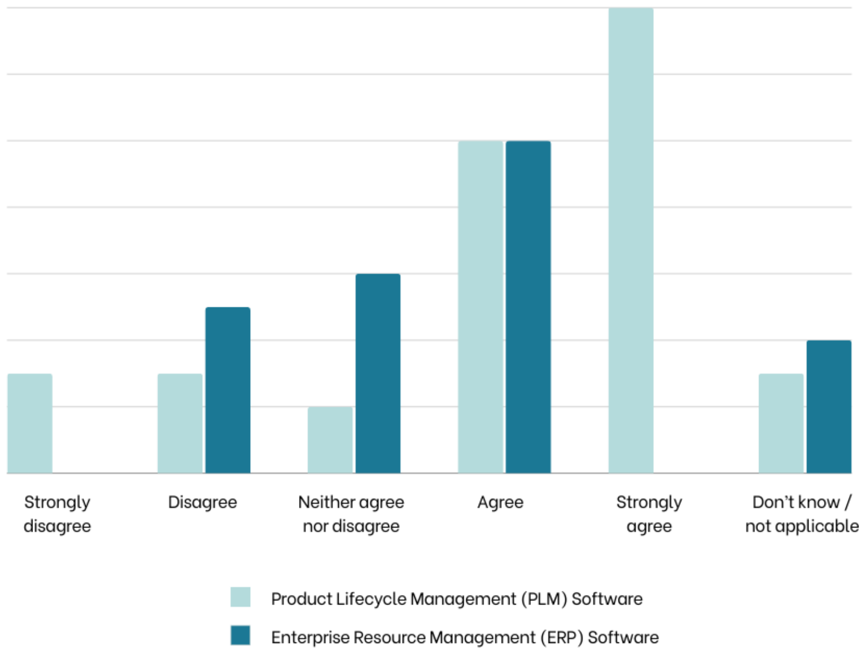


Figure 5.10 Product Lifecycle Management (PLM) vs Enterprise Resource Planning (ERP)

5.6 Impact of the COVID-19 Pandemic

As discussed in the literature review, the COVID-19 pandemic has accelerated digital transformation and the use of digital technologies, particularly 3D design software, in the fashion and apparel/ garment industry. Therefore, this section examines respondents' perceptions of the COVID-19 pandemic's impact on their organisations.

Respondents were asked *Q22. Has the COVID-19 pandemic resulted in increased use of 3D prototyping technology by their company?* Most respondents indicated an increase: (x13) respondents agreed, and (x10) strongly agreed (See Figure 5.11).

However, some respondents note that the technology was implemented prior to the COVID-19 pandemic. However, Respondent SR035 highlights,

> *There is a constant need to adapt those systems. 3D technology has an impact on the workflows and is a game changing technology. We started in 2016 to implement technology in the current process, but since COVID-19 we know, 3D technology might change our processes and the way we work together internally and with our partners.*

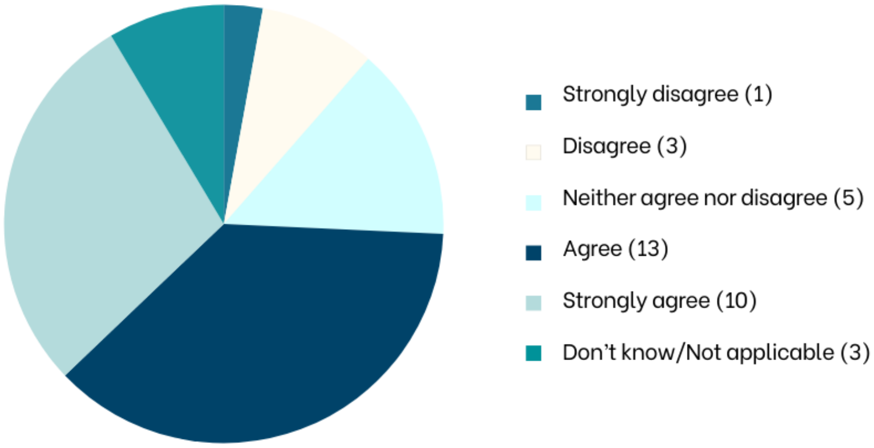


Figure 5.11 Impact of COVID-19

Respondents were also asked whether the COVID-19 pandemic accelerated their long-term plans to adopt the use of 3D prototyping technology. Interestingly, many respondents indicated acceleration: (x12) respondents agreed and (x14) respondents strongly agreed (See Figure 5.12).

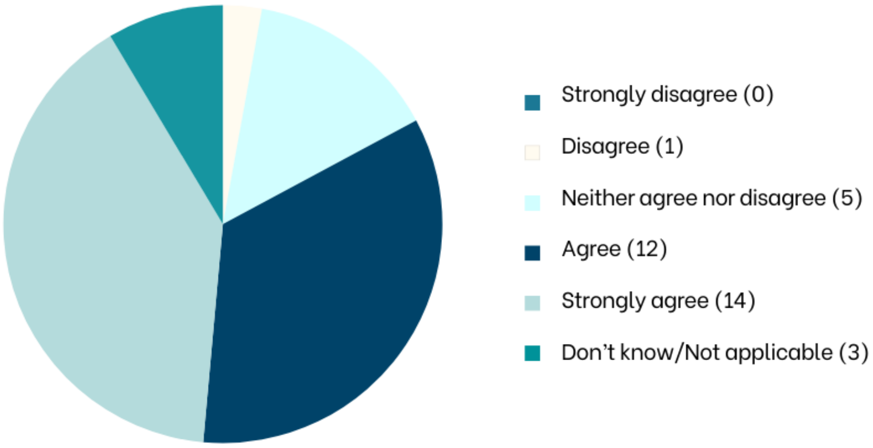


Figure 5.12 Acceleration of 3D Prototyping Technology Adoption

5.7 Summary of survey findings

The survey results reveal an overall positive attitude among respondents towards virtualisation and digital transformation. Despite the barriers and challenges, most respondents recognise the potential benefits. The findings align with existing literature on technology adoption, highlighting several key themes:

- Most IT is not compatible with the required digital technologies to support virtualisation.
- The fashion and apparel / garment industry lacks the technological infrastructure required for implementing complex virtual systems and digital technologies compared to other product industries.
- There is a recognised need for a shift in organisational culture and educational initiatives to effectively integrate advanced technologies.

Additionally, the study identified factors facilitating virtualisation and technology adoption, including the impact of COVID-19, the increasing use of 3D design software, and the need for operational excellence in the fashion supply chain. Moreover, The study led to some interesting insights, such as:

- Some experts feel that a lack of understanding of current digital technologies and virtualisation has resulted in flawed applications within business implementation.
- Terms such as New Generation Computing (NGC) and 3D Digital Product Creation (DPC) emerged, which were not considered during the survey period and will be investigated further.

This survey is the initial stage within the methodology in this PhD study, and its results have influenced the next stage of designing the interview framework. It is acknowledged that the sample size for this study is not large enough for direct comparisons among the roles identified in Section 5.1. However, the survey has identified respondent groups essential for the next step in the methodology. Most of the survey respondents hold managerial and directorial roles, suggesting they may not be the primary users of technology in their day-to-day activities. Therefore, interviews will target designers to gain their perspectives on how virtualisation and digital transformation will impact the design process, aligning with the PhD themes of craft and authenticity. This will also be observed during the case study method.

Additionally, the survey identified themes to explore further in depth, such as the enablers and barriers of virtualisation and related technologies. Respondent SR014 commented, *"Digital can help environmental protection to reduce wastage."* As discussed in *Chapter 2 Literature Review,* digital technologies are predicted to support environmental sustainability. However, the motives behind adopting digital technologies for this purpose need critical consideration, which will be explored further in the personal interviews.

Given the disruptive and evolving nature of technology, the survey underscores the importance of educating stakeholders and fostering agility in a digitally driven world. Respondent SR025 comments, *"Digitalisation is a continuing journey that will always be changing, and we will always have to adapt and improve."* Based on the survey results, the majority of the industry is at the initial stages of digital transformation. Respondents acknowledge there will be challenges; however, the overall attitudes towards virtualisation and digital technologies indicate that the benefits outweigh the challenges.

Chapter 6 Interview report: findings and discussion

6.0 Introduction to Chapter 6

This chapter presents a summary of the interview findings. The purpose of the individual interviews was to explore how virtualisation of traditional business activities is being implemented and addressed. The interviews provided insights into ‘what works’, what could be improved, and why.

In this study, the term 'virtualisation' is to mean: the process of creating a 'virtual' (i.e. 3D computer-based) model of a physical object, and how this virtual model is used throughout the product development process and beyond – for example in marketing, retail, and so on**.** 'Digital transformation' is defined as: the integration of digital technologies within all areas of a business, such as new product or service development, production, marketing, and sales. This may include the use of technologies such as 3D modelling and virtual reality.”

The interview questions were developed from a combination of themes identified in the literature and topics covered in relevant industry conferences and webinars. Two strategies were adopted to identify and develop interview questions:

- **Strategy 1**: Review survey questions, identify those needing clarification for deeper understanding, and redesign them to prompt discussions for qualitative data collection.
- **Strategy 2**: Review survey responses, note interesting responses, and formulate follow-up questions based on those responses.

A semi-structured interview format was selected to provide structure while allowing participants to expand on the topics covered. See Appendix D Interview question routes. From the survey, two groups of participants were identified for the interviews:

- **Group 1**– Consultants, Managers, and Directors (15x)
- **Group 2**– Designers (15x)

These groups will be referred to as ‘Group 1’ and ‘Group 2’ throughout this chapter for comparison and reference. In total, (x30) personal interviews were conducted.

For a more in-depth understanding of the methodology, see *Chapter 4: Methodology.* The participants are located globally across 15 countries and represent a range of sectors within the fashion and apparel / garment industry. For a full list of job roles and main responsibilities of each participant, see Appendix E: Table 1.0 and Table 2.0.

To understand how 3D design technologies are used, participants were asked *Q2. What is your role in relation to 3D design technologies in your company?* In Group 1, the main responsibilities are to lead, manage, and consult their teams or customers in utilising 3D design technologies. This includes implementation of 3D design software, offering support, and ensuring targets are met. Most of Group 1 occasionally spend little to no time using 3D design technologies within their role. Only one participant in Group 1 reported using 3D design technology daily, as a key function of their role. However, some of the participants from Group 1 expressed a desire for their roles to allow more time to utilise 3D design technology. As leaders of their teams, Participant CMD015 and Participant CMD08 emphasised the importance of having practical experience and knowledge. Participant CMD015 states, *“It’s one thing to lead a project from afar, but to have credibility, basically you have to be able to do it. That way you’re involved in it.”*

Group 2 participants carry out traditional responsibilities of garment product development. Out of the (x15) participants, (x14) participants spend 50% or more of their time utilising 3D design technology. Group 2’s use of 3D design technology will be explored in more depth in this chapter.

The following sections will discuss the findings, organised in themes based on the interview structure and additional themes that emerged in discussions with the participants.

6.1 Undertaking digital transformation

When asked, "*Q5. So, do you think digital transformation is a worthwhile investment for companies in the fashion industry like yours?"* most participants agreed:

"Yes", my company is undertaking digital transformation

The reasons participants’ companies are undertaking digital transformation include:

- To support fashion organisations undergoing digital transformation
- It is inevitable for the fashion industry to overcome key issues
- Internal benefits (e.g. reduce cost, increase efficiency)
- Supports Environmental, Social, and Governance (ESG) initiatives
- Competitive advantage by increasing speed to market
- Improve outcome of final garments to achieve true design intent
- Customers are demanding suppliers to adopt digital technologies
- Profit driven and monetary gains
- In response to the COVID-19 pandemic and political risks.
- To implement Industry 4.0 initiatives
- Fear of being left behind
- Traditional processes are outdated and inefficient
- Opportunities for new business models
- To understand the customer's wants and needs
- To increase delivery speed

Some participants are unsure why their companies are undertaking digital transformation, as it has not been clearly communicated. However, they speculate similar reasons as those mentioned above, such as inevitability of change, monetary gains, and external factors such as supply chain dynamics.

When asking participants, "*Where are you in regard to implementation: trial, beginning, middle, near completion,"* many reported being at different stages of digitalisation and utilising 3D design software. Most of the participants say they are at the beginning or in the middle of their digital transformation. For example, Participant DP07's company has successfully developed a workflow for creating products digitally but considers the company to be in the middle of implementation. Participant DP07 explains, *"So while the workflow for a style or product is very fine tuned, the expansion of all the other areas still needs to be ironed out. It's exciting."*

Many participants explain their current roles are laying the foundation to begin creating products digitally by developing digital asset libraries – consisting of a company's basic garment blocks – and digitising main fabrics. Regarding the overall industry, many of the participants feel that the industry is at the beginning of digital transformation, as it heavily relies on physical processes rather than digital technologies.

"No", my company is not undertaking digital transformation

Two participants said their organisations are not currently undertaking digital transformation. This prompted, "*Q6. What factors do you think might result in your company deciding to undertake digital transformation?"* Despite Participant DP04's team utilising 3D design software daily, digitally transforming the company is not a companywide initiative. In a previous discussion, Participant DP04 alludes to resistance within the organisation as the VP of design prefers working in the traditional way. Participant DP04 suggests that once the technology is fully developed, the company will undergo digital transformation and expand to other areas – such as digital fit.

Interestingly, Participant DP08 explains most of the software the company is currently using is in fact *'new'* to the company. The company is currently exploring technologies and would be open to 3D design technologies. As a small company, Participant DP08 assumes, this might explain the interest and eagerness to seek new technology. In addition, Participant DP08 mentions there are a few reasons the company would undertake digital transformation such as follows:

- Cost and resource savings
- Competitors adopting 3D design technology
- Environmental purposes
- Reducing travelling to factories

In addition, some of the participants explain they are not undertaking digital transformation because they were *"digital from the start".* One participant's company was founded on the notion of a digitally focused and unconventional microfactory. Other participants are software vendors or consultancies helping organisations undergo digital transformation.

6.1.1 The term 'digital transformation' needs a standard definition and set parameters

Interestingly, when discussing digital transformation, many participants criticised the term itself and considered it a 'buzzword' and ambiguous. A need for a standard definition with established parameters was raised. Participant CMD03 states, "*A lot* *of people speak of digital transformation, so it can be loosely defined, and people can get carried away with this fancy term."* Interestingly, Participant CMD01 feels the term can be deceiving as it places emphasis on 'digital', and not enough focus on 'human' transformation. Instead, Participant CMD01 suggests digital transformation should be defined as, *"The redefinition of existing processes to drive sustainable compounding growth, and to be more lean, efficient, and optimisation of all these things."* For some participants, the term is not used, but is considered a strategy to identify enablers which unlock speed and agility – such as virtualisation.

In addition, the definition varies regarding the sector, and the responses reflect this. For example, Participant CMD02's company is undertaking digital transformation, but emphasised it from a manufacturing context. The participant explains as a manufacturer, the needs and challenges of digital transformation are different in comparison to a brand. Similarly, Participant CMD010 explains that their company is undertaking digital transformation, but not from 'concept to consumers' – as in design, make, sell – but from concept to marketing.

Some respondents began to discuss digital transformation in the context of conducting day-to-day business operations. For example, Participant CMD07 states, "*If you really look at the question of digitally transforming in the way that we do business, this is completely aside from 3D and CADs."* Participant CMD07's company operates fully virtually and assists other companies in undergoing digital transformation. Alongside their brands, the organisation is also transforming how it works by operating virtually. The company's physical office is based in New York because many design offices are located there. Participant CMD09 comments,

> *Actually, it's funny. Even though we're pitching a digital product, I would still be going to their offices to show them stuff on my laptop in person, sitting next to them. That's the way they're used to seeing things…Even though it was on the screen, they still had that expectation.*

In addition, Participant CMD09 explains it is traditional industry practice to expect physical samples carried in large suitcases / trunks to be placed on hangers for buyers. Hence, it will take time before the industry accepts 3D digital prototypes. Participant CMD09 states, *"We are pushing our customers to do things digitally, but* *at the same time we have to sharpen our tools to make it even more digestible for our customers to accept it digitally."*

Interestingly, Participant DP08 is unsure if their company is undergoing digital transformation; however, other departments might be. For example, the marketing department is seeking a tool to assist customers in finding the correct fit. Regarding digitising product development, there are no current plans. Despite the company not utilising 3D design technology, the participant notes that the company heavily relies on digital technologies. Participant DP08 explains,

> *Everything is quite digital for us anyway. All the specs, size charts, and patterns are done on the computers. They're sent over to the factories digitally. Not sure if there's anything else that we could be doing, other than going into 3D.*

For this study, digital transformation was placed in the context of 3D design technologies, specifically regarding product development. However, Participant DP08 raised an interesting point that some processes and product categories within the industry are already digital despite not working with 3D design technology.

6.1.2 Digital transformation is a worthwhile investment

All participants agree digital transformation is a worthwhile investment for many reasons. Some participants feel digital transformation is critical and inevitable for the industry. CMD010 states, *"If companies don't adopt it now, they're going to struggle to survive in the future."* With hesitation, Participant DP09 agrees digital transformation is a worthwhile investment. The challenges the participant faced at the start with changing mindsets is reason for the hesitation.

Despite Participant DP08's company not undergoing digital transformation, Participant DP08 feels it is a worthwhile investment in regard to staying competitive, encouraging environmental sustainability, and offering better products for the end consumer. Specifically, the participant feels digitally transforming product development would be beneficial for the category of workwear.

Interestingly, some participants state *"digital for the sake of digital"* is not a worthwhile investment. Participant CMD03 states,

> *There's only so far technology can go unless put into the right contexts, applied by the right people, into the right process…So if you just bring 3D because everyone is doing it, let's call ourselves the digital transformation team, I wouldn't say it's worthwhile.*

Participant CMD01 also feels companies are quick to invest in 'over-hyped' technology trends (e.g. Web3, NFTs) to 'drive digital transformation'. Participant CMD01 states, *"We love to mention it in financial reports because that brings the right kind of investments."* However, Participant CMD01 argues that fashion organisations often neglect to invest in their stakeholders who will develop new processes and will interact with the technology on a daily basis. This in turn could impact the success of an organisation's digital transformation plan. Participant CMD01 states,

> *Probably 30% of all digital transformation projects across companies succeed – which means the other 70% fail. One thing I keep seeing lead to failure is those who focus heavily on technology investment. Technology for the sake of technology.…When you have people that believe that digital can really help them achieve anything then technology just naturally comes…*

Therefore, Participant CMD01 recommends that gaining a strong understanding of technologies impact workflows and what it entails will lead to success of any digital transformation project.

6.1.3 Advantages and benefits

The majority of participants feel that the advantages of digital transformation outweigh the disadvantages, with some describing the benefits as *'endless benefits'.* See the Table below for key advantages and benefits:

Advantages of Digital Transformation in the Fashion Industry
Time savings in decision-making process leading to faster turnaround.
Cost savings in fewer prototypes, logistics, and DHL parcel
Support for designers: in professional development and better use of time, experience, and understanding of product creation. Enhances creativity.
Quick prototyping and visualisation of design ideas

Reduction in travel to and from factories
Unlocks real-time collaboration capabilities
Allows time for testing garment performance (e.g. activewear) for longevity and quality
Improves communication of true design intent through realistic visualisations
Supports ESG initiatives
Enhances consumer experience and engagement in retail through an interactive experience with AR and VR
Optimisation of processes by replacing manual tasks with digital processes
Agility and speed to respond to consumer needs and industry challenges, such as overproduction
Improves communication between teams – especially international teams
Competitive advantage within the marketplace
Opportunities to support new business models (e.g. pre-order system).

Table 6.1 Advantages and Disadvantages of Digital Transformation

6.1.4 Challenges and barriers instead of disadvantages

When discussing the disadvantages of digital transformation, participants mentioned loss of 'physical touch' and potential job loss. However, most participants felt there were more challenges and barriers to digital transformation than 'disadvantages. For example, the uncertainty is widely viewed as a challenge for organisations undertaking digital transformation. Participant CMD01 states, *"I think when it comes to innovation, there is the inherent realisation that innovation involves risk."*

Most participants would discuss digital transformation interchangeably with 3D design technologies and processes. The challenges highlighted mirrored those of 3D design technologies, such as lack of capital investments for technology development and the struggle to streamline workflows software and hardware interoperability issues. Participant CMD09 states, *"The problem is that organisations right now are set up to not do things digitally, especially in the apparel industry."* Other challenges and barriers mentioned include:

- Small and large organisations face distinctive challenges

- Lack of skills and understanding
- Change management and right leadership
- Change in mindset and resistance to change

Small and large organisations face distinctive challenges

Some participants discussed how the size of a company can present both advantages and disadvantages in the context of digital transformation. For example, Participant DP015 highlighted that small organisations with fewer financial resources may struggle to demonstrate a clear return on investment. Drawing from personal experience, Participant DP015 explains,

> *They have to really prove it before you do it… That's what I faced, and it was really difficult to be able to quantify what this return on investment will be to invest in some of the technologies. Some of the outlays were quite a lot.*

Participant DP013, operating as a small batch apparel production company, also faces challenges due to limited resources. Both organisations and independent designers encounter difficulties such as high initial startup costs for training and talent acquisition. However, Participant DP01 argues, "*If you do your analysis correctly and you look at how many samples you would make, it usually pays for itself. Larger organisations more so than smaller ones."* Participant DP014 believes smaller companies often achieve greater success in digital transformation compared to large ones due to their agility and streamlined structure. Despite being a small manufacturer with limited resources, Participant DP01 is confident that the organisation is ahead of large companies.

In contrast, Participant DP05, part of a large, well-established brand, expresses frustration that that large companies move *"very slowly"*. Participant DP05 comments, "*You're always a step behind from what is developing and happening outside."* The participant expresses concern that their organisation lags behind competitors but should be leading the industry in digital transformation. Personally, Participant DP05 feels 'restricted' within the organisation, and states,

> *When it comes to 3D, it zones in certain areas. We don't really necessarily look at other developing areas within 3D. There are*

> *parallels happening outside in the world. [Large brand] becomes a little bit of a bubble sometimes.*

In addition, Participant DP05 emphasises the importance of collaboration and communication when building a foundation. Participant DP05 states,

> *You kind of skip a couple of steps instead of trying to build something from the base up. People get excited and create these initiatives without necessarily having that base first, so I think that's just kind of spiralling into a lot of different issues, to be honest.*

A consultant firm was hired to assist with the company's digital transformation project. However, after the initial assessment, the consultant concluded the organisation needed to gather its various initiatives before proceeding further. Participant DP05 states, *"They realised that maybe we were still very much in the beginning…maybe we haven't come far enough in the process to seriously start to discuss these things."* The company was undergoing multiple initiatives simultaneously. Nevertheless, significant key challenges surfaced, including inadequate communication between the teams, unclear connectivity between initiatives, and difficulty in tracking progress.

Lack of digital and relevant skills in the fashion

Many participants identify the lack of skills and understanding as a significant barrier to digital transformation. Finding individuals with the 'right talent'– possessing both design knowledge and digital skills – is particularly challenging. Participant CMD010 makes the point that very few educational institutions are embedding 3D design technology skills into their curriculum. Meanwhile, Participant CMD04 emphasises that while students understand how to use 3D design technologies, they often lack professional experience. Participant CMD04 suggests, *"...we need to bring them together with work experience and technical knowledge."*

From Participant DP01's personal experience, not everyone is 'fit' to work with the technology– nor should be selected as *"some just wouldn't get it"*. However, if approached with empathy, those against the technology can still benefit. Participant DP01 explains,

> *For those that don't want 3D, there is still a morale boost for them because they're like, oh, I don't have to learn something. Maybe these are people that are five years out from retirement. We want to make them happy too. They still get the advantage of being able to see the models and DXF files, but they may not be actually using 3D.*

In addition, as the industry undergoes digital transformation, some participants believe the skills and expertise required extend beyond traditional fashion industry roles, such as data scientists. Participant CMD012 states,

> *We also need these solutions in place that are feeding data into a data foundation layer that is open to everything that can be mined by AI and machine learning. You can't make AI machine learning effective until you have architected all those solutions that are working in partnership using open API's that can gather data in that data foundation.*

Participant CMD07 also states, *"We don't just need just generic skills in someone that kind of makes beautiful things. We also need someone that actually understands the user."* Because these skills are valuable across industries, recruiting talent on the side of R&D and engineering is highly competitive. Participant CMD07 suggests the industry might struggle in this regard.

Lack of general knowledge and understanding results in fragmented' benefits

Interestingly, participants raise there is a lack of understanding about inner workings of their organisations in general – let alone digitally. This creates a barrier for successful implementation of digital transformation. Participant DP011 comments,

> *I think overall in digital transformation, there's a lot of gaps in companies and their organisational structure to really manage digital transformation in an efficient and easily streamlined way.*

Participant CMD04 explains that while there are a few key internal stakeholders who understand the processes; however, once they leave the company, the process is unclear. In addition, some participants argue there are only a few industry professionals that understand digital transformation in the 'broadest sense'. Participant CMD012 explains, *"There may be specialists in certain technologies,* *process areas, disciplines, but very few people have an oversight of the end-to-end value chain. That is hard to find."*

Without a holistic vision and understanding of digital transformation, some participants suggest this leads to fragmented benefits. For example, time savings may be visible when evaluating garment construction in real-time instead of waiting for a physical sample. However, Participant CMD09 explains, the time savings might not extend to the subsequent steps, such as presenting multiple colourways or planning product lines. Participant CMD09 explains,

> *"Then the process starts over again at the next step at design. Or maybe design came first and then type design has to start over again. It's fragmented like that…You're still making a physical proto. You're still kind of doing things the old way."*

Participant CMD09 also explains some clients only want 3D visualisations for sales purposes. Consequently, their company has not fully digitised their design or product development processes. Some companies are only digitising repeat styles such as 'polo shirts'. Participant CMD09 suggests, *"there's just not a lot of trust there to realise the full benefit."* However, to achieve maximum benefits, some participants argue that organisations should pursue 'end-to-end' digital transformation, integrating digital technologies throughout the entire value chain. Participant CMD09 explains, "*Even though brands and retailers that are quote-un-quote have the most developed 3D programs are not really doing it end-to-end."*

Despite participants mentioning numerous benefits of digital transformation, some acknowledge they are not necessarily seeing all the benefits. Participant CMD03 explains that if carried out properly, digital transformation has the potential to be 50% faster than the existing process. However, Participant CMD03 admits that their company has not yet fully achieved full capacity but remains optimistic that alignment of workflows and pipelines will facilitate it. Given that many organisations are still in the early stages of their digital transformation journey, measuring and demonstrating return on investments remains challenging.

Change management– the right leadership

The importance of change management was strongly emphasised as a critical factor in successful digital transformation, as leadership plays a pivotal role in determining the project outcome. Participant CMD09 states, *“A lot of this is not necessarily about software, it's more about mindset change and change management.”* Even so, both are challenging and demanding factors to achieve. Participant DP015 echoes this sentiment, stating, *“It's a challenge that I've seen in every place I've worked, and I don't have the answers. It's hard to get over.”* Change management aims to support stakeholders in adapting to new processes and understanding their needs. Participant DP011 comments, *“I think the biggest one is the emotional impact of change. It’s really married with change management.”* This underscores the crucial need for the right leadership. Participant DP03 states,

> *I think you have to have the message come from the levels above then trickle down. Otherwise, there's a lot of people involved in the supply chain, and if you haven't got those big goals at the top, it's difficult for people to incorporate.*

For example, prior to Participant CMD08’s company undertaking digital transformation, the participant expressed frustration in persuading leaders to prioritise 3D design technology. However, after hiring a new Chief Technology Officer with prior experience implementing 3D design technologies, Participant CMD08 observed a significant shift. The CTO became the main executive sponsor. Participant CMD08 shares,

> *Before I'd done numerous presentations about the benefits it would bring, but people were a bit scared of it. They didn't know how to handle it. It was like a hot potato they kept throwing around, and nobody wanted to keep hold of it.*

Participant CMD08 feels confident in the direction of the organisation with the new leadership. The company has now initiated a companywide plan to develop the use of 3D design technologies in teams that are *“equally engaged”*.

Resistance of customers and designers– changing mindsets

Changing mindset from the traditional way of working is challenging, given the industry's historical resistance, as reviewed in the literature. Participant CMD015 states, *“Would some companies change just for the sake of change? The apparel industry has fought tooth and nail forever.”* The ‘human’ element can be a barrier. Participant DP014 states, *“Most of the time it's not the technology. It's the people that really don't make it work.”*

According to Participant CMD015, two primary factors contribute to resistance in digital transformation: 1) The technology is not mature enough 2) Lack of understanding within business culture. Regarding technology, software is expensive and carries implications, such as with other capital expenditures. As for business culture, Participant CMD015 criticises that ‘workforce development’ is not being considered as automation will lead to a different way of working. Additionally, C-Suite and management need to think differently. Participant CMD015 explains,

> *What worked in 2005, doesn't work in 2022. Since we don't manufacture in the US, they don't understand that when companies used to be vertical the same company that owned a design group also owned manufacturing. There was an understanding of how stuff was made across the board, but now it's halfway around the world.*

In Participant CMD07’s opinion, most of the industry is not interested in changing nor thinking differently. Participant CMD07 states, *“Sometimes I just feel like there's just so much headwind when you're going around and speaking to brands. They're like 'oh yeah this is really cool ‘but...’.”* As many participants have pointed out, change is uncomfortable and met with resistance. Participant DP04 states, “*Some people are very stubborn in their ways. If it's not broken, don't fix it.”* Echoing this sentiment, Participant CMD013 makes the point that large companies want to keep what they have been doing but is contradicting as they demand more efficiency. Participant CMD013 states, “*They don't want to do it differently. Part of it is the tech, and what's driving the tech isn't innovation. It's existing embedded practices.”*

Some participants find convincing others to begin digital transformation or accept 3D digital models over physical prototypes to be a daunting task. Participant CMD09 states, “*Changing the process I think is 90% of the battle to getting a new customer* *to adopt digital."* Brands and retailers are not modifying their time and action (TNA) calendars to account for faster digital prototypes versus what could be achieved physically.

Moreover, Participant DP014 has encountered teams frequently comparing the new process with the original workflow; however, they are incomparable. This often leads teams hesitating, fearing failure, or making excuses. Participant CMD03 states, *"It is easy to kind of pinpoint and say, oh, technology is not there yet. So, we'll do it once it's ready."* Additionally Participant DP014 has faced mental strain when dealing with client resistance towards digital technologies. Participant DP014 states,

> *I was faced with very challenging questions in my previous position while I was doing demos. As a creative person to face these types of harsh questions and conversations, it's a creativity killer for me. That's why I was like, 'I need to go to a more creative team'.*

Based on the insights from this section, it is evident that digital transformation in the fashion industry faces numerous challenges and barriers. Despite these hurdles, participants express optimism regarding the many benefits. From the discussion, it is clear that the challenge extends beyond hardware and IT issues. The primary key for success lies in the human element, specifically in nurturing stakeholders throughout the transformation process.

6.2 COVID-19 pandemic accelerated decisions to undertake digital transformation

As seen in Section 6.1, some participants are undertaking digital transformation in response to the COVID-19 pandemic. Supply chains were *"dismantled overnight"* as vendors and suppliers were forced to close. With physical sample runs and production at a standstill, some design teams relied on using 3D design technology to carry out virtual fittings. Participant DP07 states,

> *I don't think 3D would have grown as fast without depending on it. People were working from home not being able to interact with each other. It was the glue that kept everything together.*

3D design technology proved useful, and some explained the pandemic removed doubt or hesitation design managers had prior to the technology. For example, at an annual conference three years before the pandemic, Participant CMD08 struggled to convince suppliers to accept 3D design software. Only one supplier had recently adopted the technology. Participant CMD08 comments,

> *They didn't understand it. They understand somebody sitting at a sewing machine making a sample because that's been happening for hundreds of years…Now we've got about 40 suppliers who are using 3D, and most of those have made the move in the last two years. Absolutely linked to the pandemic.*

Without a choice, the attitude towards the technology changed. Participant CMD04 had a similar experience, and states, *"Before we had so many discussions such as 'oh that avatar doesn't look nice. Is this the real colour?' But then when they needed it, no discussions…So it really was a switch."*

From the perspective of a brand and marketing agency, Participant CMD014 explains brands were also forced to digitally transform their marketing strategies as a *"survival instinct"*. Participant CMD014 shares,

> *When the pandemic first kicked in, all our clients pulled every contract and people panicked. However, within a week everyone signed right back on again because they realised this is actually the time to work on marketing, websites, or graphics.*

Participant CMD014 suggests competition is what drove brands to digitally transform as they closely followed their competitors' ecommerce and social media platforms.

6.2.1 Digital transformation prior to the COVID-19 Pandemic

Some participants began their digital transformation efforts prior to the COVID-19 pandemic; however, the pandemic confirmed it was the right investment. Participant DP05 states, "*The benefits were definitely much more visible and clear when the pandemic hit.*" These participants found it easier to *'carry on as normal'* during the pandemic, and it continued to be valuable afterwards. For instance, Participant CMD03's company saw the number of styles per year double after the pandemic. Participant CMD03 states, "*I would say we wouldn't be able to have done it overnight had we not built this capability five years ago."*

Some participants believe digital transformation would have occurred without the pandemic. However, the pandemic accelerated the pace at which various sectors of the industry embraced digital transformation. Participants are seeing digital initiatives expand into other areas of business. Over the past three years, Participant CMD010 has seen the industry grow *“roughly the equivalent of 5 to10 years in the digital transformation, or at least in awareness acceleration.”* Participant CMD010 feels the industry has changed more in the last five years than it ever has.

6.2.2 Job loss, new roles, and collaboration

During COVID-19 pandemic, some designers experienced job loss, but those with skills in 3D design technology were in high demand. For instance, Participant DP04 was laid off during the first week of lockdown but was quickly hired to join a new 3D Digital Design Team the same week. Similarly, prior to the pandemic, Participant DP06’s former company began a company-wide initiative to implement a 3D workflow. Although training was initially optional for all staff, Participant DP06 chose to participate out of personal interest. However, during lockdown, the participants found themselves utilising the software daily, leading to rapid skill development.

Moreover, the COVID-19 pandemic led to an exchange of communication and collaboration throughout the value chain unlike ever before. Participant DP010 states, “*There was a lot of contribution from all the sides – vendors, customers, and manufacturers. It was that time things changed.”* Brands and suppliers worked with software vendors by providing feedback, such as features to speed up the process, resulting in further development of 3D design software.

6.2.3 Post COVID-19

Despite a high uptake of digital technologies such as 3D design software during the pandemic, some participants believe this is not an accurate representation of the industry as a whole. Over the last five years, Participant CMD09 explains, *“I think adoption is still extremely low…I'd say over 95% of the brands and retailers out there are doing it the traditional way.”* As discussed previously, the lack of capital to invest in research and development of 3D design software is a barrier to adoption. Participant CMD015 states, *“Our industry is huge. We'll always wear clothes, so* *there will always be a continuing need. It's probably the last big digital frontier that could go from zero to build the whole thing."*

As a result of being forced to invest in digital transformation, some participants are concerned that the fashion industry will return to its traditional process once business returns to normal. Participant DP010 states, *"The hype we had around digital product creation during COVID-19 situation is now somewhat stable… it's slowing down."* Participant DP010 explains that convincing some customers to adopt 3D design technology is still challenging. Regardless, many of the participants state their plans to invest in digital transformation are long-term as it is important to gain return on investment of operating expenses. Participant DP03 states, *"They want to continue training people up and eventually the whole design team will be doing 3D."*

Moreover, Participant CMD012 has many years of experience working with organisations undertaking digital transformation. Very few look at a one-year strategy. The participant explains that many small and medium-sized enterprises (SMEs) plan one to three years as the first step in digitally transforming. Whereas large global organisations plan one to ten years to complete digital transformation. Interestingly, some participants shared their next steps regarding digital transformation such as follows:

- Expand digital transformation initiative to all product categories to achieve end-to-end product development.
- Seek and implement other virtual solutions that support 3D design technologies and digital assets (e.g. PLM software, avatar development, fabric digitalisation).
- Offer consumer facing virtual experiences and interactive engagement (e.g. virtual fittings, 3D assets on ecommerce platforms, virtual worlds (e.g. the Metaverse).

A few participants are unsure if digital transformation is a long-term strategy, but current goals of building a digital foundation to support virtual prototypes alludes to a long-term strategy. For example, the process is fully integrated into their day-to-day job roles. CMD010 states, "*I just don't know how far they really want to take it."*

Additionally, Participant CMD02 is unsure, but digital transformation is mostly likely part of a long-term strategy from a manufacturing and automation perspective.

6.3 Organisations will digitally transform – envisioning the future industry

As the industry is at the start of undergoing digital transformation, participants were asked, *Q6.3 What will your company look like once digital transformation is complete?*" Some participants explain they were unsure as there is no clear vision. Others state that no one truly knows; however, it will continue to evolve. Interestingly, most of the responses were similar such as follows:

- Digital transformation will *never* be complete but will continue to evolve.
- Achieve end-to-end in the context of a digitised and connected process consisting of 3D design technologies and access to product information stored in one platform (e.g. digital asset libraries, product passports).
- Consumers will take part in the product development process enabled by a 'pre-order system' and 'made-to-measure' business models. Customers will have a digital twin avatar.
- The participants' companies will be digital leaders within their sectors.
- Increased efficiency, leanness, and agility by reducing time in sampling and shipping enabled by digital technologies.
- As the wider industry adopts digital transformation, Participants' current businesses will evolve and adapt to meet different needs along the implementation process.
- Access to digital technologies will be open to the public and for all to explore.
- A blend of the physical and digital world – The '*Phy-gital'* world (i.e. Metaverse, Web 3.0).

Interestingly, some participants began describing their physical offices. Given that many fashion organisations operate in silos, some participants envision a shift away from structured office spaces that divide departments. Instead, digital transformation will require a collaborative physical workspace with clustered desks in one space. Another participant suggested a hybrid method that allows remote work facilitated by a single collaborative platform, regardless of location. These participants believe these changes would foster greater collaboration across functional teams, improve communication, and strengthen relationships between brands and vendors.

6.4 Virtualisation is seen as a worthwhile investment for companies

After exploring digital transformation, the conversation shifted to virtualisation. Unanimously, the participants agreed virtualisation is a worthwhile investment for many reasons. Participant DP07 states,

> *It targets a lot of different issues at the same time… it's like a Swiss army knife. It can be applied to all kinds of different things from that one body and applied to all different types of platforms and parts of the workflow.*

In addition, virtual assets were suggested to have *"exponential uses"* and support a variety of processes such as product development, marketing, and design. Benefits of virtualisation mentioned by participants include:

- Essential for maintaining competitiveness.
- Mitigates external risk (e.g. pandemics, political instability, supply chain issues).
- Enhances consumer value.
- Facilitates consumer engagement and interaction (e.g. virtual try-ons, Metaverse).
- Drives ESG initiatives.
- Enables new business models and processes.
- Enhances real-time communication and collaboration.
- Enables idea experimentation and prototyping before physical production.
- Promotes personal development and learning.
- Improves manufacturing efficiency and speed.
- Enables rapid prototyping and informed decision-making for high quality products.
- Enhances data collection and insights into product performance.
- Streamlines product development processes.
- Supports *'unlimited creative freedom'.*

In regard to barriers of virtualisation, responses are similar to the barriers to digital transformation. Many of the participants recommend that organisations consider multiple factors – which might in turn result in barriers to virtualisation if not careful. Barriers of virtualisation mentioned by participants are as follows:

- Leadership lacking understanding and skills of virtualisation.
- Insufficient budgets, resources, and time for training / upskilling.
- Failure to nurture collaboration and stronger relationships between vendors.
- Lack of clear goals of virtualisation initiatives.
- Emphasis on short-term investments over long-term strategies.
- Inadequate investment in suitable or updated hardware.

6.4.1 Virtualising the whole product development process – is it needed?

Many participants feel virtualisation of the whole product development process is essential. Participant CMD02 states, *"I feel frustrated…I don't know why it's not used much more aggressively and faster."* Like digital transformation, some participants discuss that virtualisation must be carried out end-to-end beyond product development to gain benefits.

Participant CMD013, however, finds virtualisation of the product development process valuable, but disagrees with the current way it is carried out. The participant suggests that marketing the virtualisation of product development and the emphasis on innovation are partially to blame. Participant CMD013 states, *"Innovation is only going to be supported if it gets traction, and it struggles to get traction. I think that becomes a sort of perennial issue."*

Other participants feel that only parts of the process *should* or can be virtual. Participant CMD06 argues, *"It's about going digital where it makes sense to be digital to get the benefits. Things that have to be physical, keep those physical."* If a garment is created for the Metaverse or gaming, some participants agree the whole process can be virtual. However, physical touch and the handling of fabric cannot be replaced. One participant highlights that the actual production stage is still a manual process, and similar to other responses, the physical sample is still needed to confirm the process such as the 'top of production' sample – first garment run to ensure quality. CMD010 explains,

> *Some people would argue with me, but you run into challenges if you haven't physically checked it yourself…Unfortunately, I just don't think our industry is set up to fully trust that the physical product comes through looking like it should.*

Some participants, however, are seeing organisations aim to completely remove physical prototypes altogether. Participant DP03 states, "*One of our customers has a goal for 100% of initial samples and sign offs to be in 3D by the end of the year. So, it's quite an ambitious goal."* One might argue that specific product categories that require minimal changes per season could potentially remove physical sampling altogether. For example, Participant DP03's team has reduced physical sampling significantly – specifically in the product category of nightwear. Participant DP03 states, *"Because nightwear is so print and graphic heavy, you're doing all your scaling in 3D before it's sampled. So, my hit rate as a designer is better because of that."* By utilising 3D design software to design, present ideas, and sign off, at least six samples in nightwear have been reduced. In addition, the team can design closer to the time and season. Participant DP03 states, "*Usually in your critical path you build in two to three weeks the sampling. We've cut that out completely on nightwear."*

6.4.2 Virtualisation has the potential to address key issues– but only partly

Most participants strongly feel virtualisation has the potential to address key issues facing the fashion industry such as:

- Support environmental sustainability (the most mentioned)
- Support social issues: diversity, inclusivity, and democratisation of fashion
- Rebuilding the fashion supply chain
- Transparency and traceability

With virtualisation and digital transformation combined, Participant DP011 states, *"They really help solve a lot of those issues and open the door wide enough for us to find the solutions that we've been failing in these spaces."* Nevertheless, some participants emphasise that virtualisation alone is not a full solution, but an important tool to partially solve these issues.

A separate group of participants feel virtualisation is irrelevant in the discussion of the issues the industry is facing. Despite virtual technologies' potential to reduce waste during the product development process, some participants argue the general fashion industry and consumer culture needs to change. For example, consumers should choose 'slow fashion' as opposed to 'fast fashion', or to utilise data analytics to make an informed decision on what consumers want as opposed to guessing. Participant DP01 states,

> *It's more about how much we're producing, and how we're going about doing it…I don't think we would be naive to think that if you just incorporate 3D and virtualisation, then it's going to eliminate all of the world's fashion industry waste. No, because there's still fast fashion that is degrading the planet.*

Despite the majority feeling positive that virtualisation can support environmental sustainability efforts, Participant CMD015 feels differently, and states, "*When it comes to sustainability in the environment, the answer today is that it has literally no impact whatsoever. That's not the way it could be…"* Participant CMD015 explains there are two ways brands design garments. The first is based on the popularity of previous brands; therefore, the brand will create adaptations based on what sells well. The second is driven by sourcing or where products can be made based on the best prices and the least tariffs. If the industry wants to address sustainability, Participant CMD015 suggests the industry should focus on *"operational excellence"* in addition to defining the term and establishing parameters. In Participant CMD015's opinion, investing in virtualisation is mainly driven by profit and reducing expenses. Participant CM015 states, "*The fact of the matter is they're getting killed when it comes to running a business."* However, Participant CMD012, argues profitability is not negative. Participant CMD012 states, *"All those efficiency gains actually, in parallel or sustainable gains…It's not about just increasing your bottom-line profit, but all the other benefits it delivers from an operation."*

6.4.3 Virtualisation to bring new issues for the industry

Most participants agree virtualisation will create new issues. Several participants state everything new brings more challenges – a positive and a negative. Participant CMD09 states, *"I don't think we've done enough of it to uncover all of the issues it* *will bring, but of course there will be different objections that come for different issues we have to solve."* However, Participant DP013 firmly believes the "*good outweighs the bad"* as there are more advantages. Interestingly, Participant CMD01 *hopes* it creates new issues to push innovation, new ways of thinking, and creating new processes. Participant CMD01 states,

> *I think virtualisation will make the process a lot more transparent. Where we thought there might be a hole, we will see it. Where we might think there might not be a hole, we may actually see something we don't want to.*

Furthermore, challenges of digital twin modelling are mentioned by many participants. They are concerned virtualisation may create further issues such as:

- Further negative environmental impact.
- Require more energy consumption.
- Overwhelm consumers with *too* much product virtually.
- Removes physical skills and the 'craft' of products.
- Results in job loss, internal conflict, and a skills gap.
- Distracts problems of the physical world with a virtual world.
- Challenges ownership, legal issues, and international policy.
- Creates 'digital' waste and leads to burnout.

In addition, some issues are expected to continue. Participant DP07 explains that the need for continuous investment in upgrading hardware remains a significant challenge, as many organisations fail to prioritise it. Participant DP07 states, *".... that's the bottleneck if the hardware can't run it."* Participant CMD04 also highlights the challenge of managing large sets of data and having a server that can handle large amounts of data. The company's server is often full, creating ongoing problem for the IT team. For this reason, Participant CMD04 suggests,

> *You need to find a way to have lean data. Not to produce duplicates or copies of your model. To have different versions, and then you have to delete. So, you need a clear IT structure. To have your data updated, but not overloaded. We need standards.*

6.4.5 Virtualisation might raise issues for designers– Group 1's perspective

Virtualisation will require the industry to reconsider a series of factors. Job roles and responsibilities will need to be redefined, and curriculums in fashion education redeveloped. In addition, the role of the fashion designer and technical/pattern makers might merge into one. From the perspective of Group 1: Consultants and Managers, and Directors, participants mentioned several issues virtualisation might raise for designers such as:

- Designers with years of traditional industry experience might struggle to adapt.
- Working virtually will require a new way of thinking (i.e. engineering and creative).
- An increase in workload as the industry transitions.
- Upskilling will be required alongside carrying out usual workload.

Designers are the most likely to resist virtualisation, as they might feel threatened. Participant CMD09 has experienced receiving objections from designers who do not utilise basic pattern blocks, as it is considered 'not creative enough'. Participant CMD09 states,

> *I totally get it. They feel that this is robbing them of their creativity, or their value is less because they're designing from something existing. That as a non-designer I see it as you're still designing something new, but you're not starting from zero.*

Participant CMD09 feels this virtualisation allows designers to unlock creativity as it allows more time to focus on new styles. However, some designers take pride in starting whole collections without patterns. Convincing these designers to think differently is challenging.

6.4.6 Designers' response 3D design technologies are impacting their role

The responses above are supported by Group 2 Designers', who raise similar challenges regarding the impact of 3D design technologies on their roles, such as an increase in workload. Participant DP010 states, *"For me the role is always the same, but the work tasks I had to take on gradually increased."* Interestingly, most participants in Group 2 are expected to take on leadership responsibilities, support colleagues working with 3D design technologies, and carry out their own job responsibilities. Setting aside time for designers to learn and develop new skills is challenging. Participant DP06 states, *“There's no kind of extra time in the calendar to allow for the designers to learn this new way of working.”* This adds strain on designers. Participant DP07 comments feeling constantly challenged to learn daily as the technology continues to develop. Participant DP07 states, “*You want to be faster, efficient and better.”* However, this could result in fear as new virtual technologies can be seen as a threat. Participant DP05 states,

> *I think fear is definitely one of the keywords that I get from a lot of people. They are afraid of what that means for their role, their industry, and their creativity. No longer having that kind of touch and feel process.*

Participant DP014 argues that virtualisation creates more job opportunities. Similar to hiring a fashion stylist or photographer, Participant DP014 explains their skills are still highly valuable, and states, *“Every asset could be used in a different way, with different people, and with different specialties.”* In addition, many participants feel designers should not fear being replaced by technology as they are crucial in the creative process. However, this would mean designers will need to transfer their physical skills into a virtual process – which requires a different way of thinking. Participant DP05 explains that utilising 3D design technology forces designers to understand patterns and garment construction instead of relying on the technical team. Designers will need both 'engineering' and 'creative' thinking skills. Participant DP012 states,

> *I think it challenges us in terms that we really push some of these designs that we're doing. Will this work and try to figure out how some things would be stitched together? It can be done in 3D, but to manufacture and produce this in bulk is definitely a topic and a challenge to work through.*

Some participants argue designers should be technical thinkers regardless because they are the first ones to shape designs from an idea to realisation. However, not all fashion designers understand garment construction. Participant DP01 warns,

> *Be fearful, designers who don't know your technical skills. Either go get educated or do something else because it makes it hard for everyone else in the work stream when a designer doesn't know those details that are needed to bring a product to life.*

Interestingly, Participant DP01 argues that 3D design technology can in fact help fashion designers learn technical skills required in garment construction. One of the main objections Participant DP05 hears from designers is *“but we’re not pattern makers”.* The participant suggests that fashion designers should at least have a basic understanding. However, Participant DP06 argues that in some situations, technical accuracy is not needed. Participant DP06 states, *“I think there's a few different ways of working within the software where you can fake a lot of things. So, it doesn't need to be technically accurate.”* It depends on the purpose of the files. If an organisation wants to use the files for production, Participant DP06 states, “*it’s kind of asking a lot for the designer.”* At Participant DP06’s company there is a senior 3D pattern designer who works alongside the fashion designers to create production ready patterns.

6.5 Virtualisation and the concepts of craft and authenticity

Overall, most participants feel virtualisation supports concepts of craft and authenticity. It allows stakeholders to visualise design intent, experiment with various materials, and explore design ideas in real-time. However, it may challenge designers or crafters to integrate new technologies into their practice. Participants argue craft and authenticity remain evident even when virtualisation is part of the process for the following reasons:

- Learning virtual technologies still requires time, repetition, and training.
- The merge of physical and virtual practice is an evolution of craft.
- Virtualisation technologies require designers to be more technically aware.
- Automating mundane tasks allows designers to focus on their craft enabling joy.
- Supports unlimited creative freedom through rapid prototyping.
- Knowledge of product and technique is craft and authenticity – not technology.
- Virtualisation is considered a tool giving practitioners control over their craft.

- An opportunity to explore new creative opportunities beyond the current intended use.

Some participants argue the 'craft' is the same, but the tools and processes are new. Others view physical and digital craft as two separate entities. Participant DP04 states,

> *I think there will always be a market for that Savile Row tailored kind of craftsmanship. At the same time that's one extreme. I feel fashion is the other, and then digital fashion is on the other end of the spectrum. There's an appreciation for both.*

Participant DP015 feels there should be a balance of both the physical and digital, and comments, *"Until we're all wearing virtual outfits in the virtual world, we still have to wear clothes."* Therefore, it is important, especially for new designers, to have an understanding of both digital and traditional craft. The participant believes focusing on one or the other will limit opportunities. Participant DP015 states, *"You still will need a better physicality because a product that you still wear is a physical product, but not embracing new technologies is going to limit you."*

Nevertheless, virtualisation raises concerns for some participants in regard to craft and authenticity. By replacing physical skills and making of products, Participant CMD08 states,

> *I worry about losing hand crafted pattern cutting skills because people are staring at a computer screen all the time. I worry about anything that I suppose cuts people's connection with true handcrafted reality in the real world.*

As virtualisation enables automation of 'drudgework' and elevates designers, Participant CMD015 raises concern of generative design replacing designers. Participant CMD015 defines generative design as,

> *A software process that identifies literally millions of possible designs, quickly processes them, and spits out only the ones that meet all the end user requirements…Generative design basically takes the human out of the design process.*

Participant CMD015 explains there are companies exploring generative design for fashion, but the participant argues against automating creativity as *"creativity is* *something that should be uniquely human."* Instead, technology is a tool to support processes. Participant CM015 states, *"Technology itself has no virtue, but more often than not, we use technology to do things badly much faster. The faster we do them, the less chance to recover when things go wrong."*

Regarding how consumers perceive fashion design as a 'craft' or the perceived 'authenticity' of products, participants feel virtualisation will not influence general consumers, as the final product is more important. One participant suggested that this is due to consumers' lack of connection with craft, as a result of fast fashion culture. Participant CMD010 argues consumers are more digital savvy and prefer to shop online. However, this may not hold true for consumers who purchase luxury and haute couture items, where handcraft, craftsmanship, and authenticity are highly regarded. These consumers may not be technology driven. Participant CMD014 explains, *"It doesn't follow the same rules. It's like how luxury has just held their hands up and said no to TikTok. I actually quite like that."* In Participant CMD014's opinion, certain techniques, and processes, such as embroidery, should be carried out manually, as this consumer market is willing to pay for the time and skill of the crafter. In addition, physical touch and quality are main competitive advantages when communicating craftsmanship. Participant CMD03 raises the concern,

> *Now if you are doing it digitally, how do we still represent that kind of craftsmanship in a digital garment? There's so much you can do to make it technically accurate and beautiful, but would it represent a physical garment?*

Participant CMD08 also argues consumers might perceive the product differently, and states, "*You can replicate the idea and the visual aspects of that on a screen. But not the actuality of it…"*

6.6 Selection of technology is affected by multiple factors – both subjective and objective

Most participants do not sign off or choose the 3D design technologies their companies adopt; however, they influence decision makers through feedback. Based on participants' responses, the selection of 3D design technologies is affected by multiple factors – both subjective and objective. Factors considered are as follows:

- The most industry wide used or familiarity of the technology.
- Accuracy of 3D modelling capability and connectivity of software.
- What their suppliers or partners are using.
- Brands will make final decisions based on stakeholders' feedback.
- The technology was already selected once joining the project or organisation.

Interestingly, Participant DP03 raised that suppliers are limited in how much technology to implement and invest in. Participant DP03 states,

> *We're quite reliant on how far our customers want to push 3D, and what our customers' goals are. So, it's not just what we want to do. It's about aligning ourselves with other businesses.*

In addition, participants highlighted disadvantages and advantages of 3D design software. A major disadvantage is that there is not currently an industry standard software. For some participants, choosing the right 3D design software required trailing multiple options, with some up to six or more solutions. Out of the interview responses, three main 3D design software solutions were mentioned. Also, many participants reported using multiple 3D design software to support different clients. A few participants identified their organisations as 'tech agnostic', or the belief there is not a single definitive technology solution.

6.6.1 A variety of 3D design technologies are used– 3D modelling software.

Interestingly, when asked, "*Q4. What 3D design technology does your company use?2*, most participants only mentioned 3D design software. It seemed that, in response to this question, 3D design technology meant 3D design software. Further prompt questions were used to identity other 3D design technologies their companies are using. Table 6.2 below includes the different 3D design technology mentioned during the interview by all participants.

3D Design Technologies (All 30 Respondents):
• 3D modelling software (e.g. CLO3D, Browzwear Vstitcher, Optitex 3D, etc) • Fabric analyser and fabric digitiser • 2D pattern digitiser • Virtual avatars for fittings • Virtual platforms for presentation (e.g. virtual showrooms) • 3D rendering software

• 3D design technology plug-ins • 3D open-source software • 3D body scanning technologies • AR and VR
Other Hardware/technologies mentioned to support 3D design technologies:
• Tools to measure fabric physics properties • R&D scientific tools to create software • High-spec gaming computers • Digital drawing tablets • Interactive screens to build garment assortments • Platform/ modelling tools to display or house 3D digital assets • AI
2D Software and non-garment related 3D design software mentioned:
• 2D Lectra (traditional for the industry) • 3D modelling software for hardware or trims • 3D CAD for footwear • 3D printers • Big data analytics

Table 6.2 Types of 3D design technology

Some participants state their companies are not utilising 3D design technology or are unsure about its use within their area of the business. One participant mentioned their company relies heavily on 2D programs: Adobe Suites, Lectra/ Gerber. Interestingly, Lectra acquired Geber in 2021, and has its own 3D design software. However, the participant explained that no changes have been made to their current package, and currently no future plans to adopt 3D design software.

6.7 Many benefits of 3D design technologies– especially for designers

In Group 1 and Group 2, many participants expressed having positive experiences working with 3D design technologies, noting that this has often led to their current roles. From a management perspective, Group 1 mentioned that working with 3D design technologies has led to new insights and better understanding of how the technology can support industry and designers' needs. Group 2 participants mentioned seeing a reduction of resources during the prototyping stage, and time savings during the decision-making process. Additionally, the participants believe 3D design technologies offer many personal benefits for designers.

For the following sections, Group 2 Designers were asked additional questions to gain insight into how virtualisation and digital transformation will impact their design process to support the PhD theme of craft and authenticity (See Appendix D, Section 4: About design).

6.7.1 3D design software and inspiration

To gain understanding of how designers feel about 3D design software, Group 2 Designers were asked, "*Q.10 Does 3D design software inspire you as a designer? Why or why not?"* The majority of Group 2 feels that 3D design software inspires them as it allows them to explore, experiment, and visualise design ideas before creating them physically. In addition, some participants find the 'process' and 'outcomes' of the technology inspiring. As a designer and craftsperson in tailoring, Participant DP013 explains,

> *3D work really brings these two fields together to one, which I think from a product perspective, is very good. As a team working in the same software will give you a better, more holistic understanding of what it is you're doing.*

Other ways in which 3D design technologies inspires Group 2 are as follows:

- Ability to visualise beyond the limitations of one's imagination.
- Provides information about the garment construction otherwise not seen physically.
- Facilitates styling and ensemble exploration.
- Enables exploration of unlimited colourways, prints and materials.
- Improves communication of design intent compared to 2D CAD image.
- Empowers control over the pattern making process without relying on a technician.
- Ensures precision in the practitioner's craft.
- Accelerates prototyping to allow for more experimentation of design ideas.
- Sparks creativity and innovation in product creation.
- Facilitates personal growth and development in design skills.
- Supports remote design creation through cloud-based accessibility.

- Provides limitless creativity without physical restraints (e.g. sewing machines, fabrics, etc).
- Allows to create what is not physically possible.
- Promotes inclusivity by designing for diverse body shapes using avatars.
- Acts as inspiration for future projects.

Several participants in Group 2 commented that using 3D design software has improved their understanding of garment construction and pattern making by allowing them to visualise how 2D patterns will behave. Participant DP05 explains, *"You actually get to see that straight away, and you can learn even more from pattern mistakes that you might make."*
In addition, some participants feel 3D design technologies support creativity and make the design process more enjoyable. Participant CMD08 explains, "*It's not like it's a really boring, sloggy process…It's just so playful, and at the same time, so powerful and impactful."* Participant DP011 explains being a designer in a corporate role can become 'siloed' and 'boring' as the role consists of one specific function. Participant DP011 states,

> *3D is really enabling more of that collaborative creative space that's quite limitless in what you can do. It really brought that back, and I've just found so much enjoyment in areas that I didn't even realise I could.*

Working digitally also reduces a designer's workload and mental stress. Participant CMD08 explains, *"They put hours, days, and weeks of work into something. In 10 seconds, somebody from the executive team has made a decision to say 'no, that's not right for us'."* Making decisions on a 3D digital prototype not only offers cost and resource savings, but it is a better use of a designer's time. Participant CMD08 states, *"It's less potentially soul destroying because you've not invested as much of yourself and other people's time into it."*

One participant, however, mentioned not finding 3D design software inspiring in a 'creative way'. Participant DP09 explains, *"I take more inspiration from historical references and creating the real product, how it feels, and how it makes you feel as an individual."* However, Participant DP09 mentioned enjoying learning new technologies and developing as a designer. Additionally, Participant DP03 finds 3D design software inspiring, but also seeks inspiration for initial idea generation outside the software.

6.7.2 Motivation is driven by the practical use of 3D design tools and personal development

When asked, "*Q11. To what extent do you feel motivated to learn 3D design tools?", most* participants in Group 2 felt highly motivated to learn for reasons such as:

- Become better as a designer and/or team leader.
- Stay ahead of the competition.
- Keep up with software developments.
- Avoid being left behind.
- Challenge oneself.
- Adapt as to industry changes.
- Out of desire and curiosity to learn.
- To create optimal processes in product development.
- 'Forced' to as 3D design tools are essential to carry out daily tasks.
- For the high salary due to the demand for 3D digital skills.

As a result of adopting 3D design technologies, Participant DP01's design team has become closer and empowered. Participant DP01 states,

> *The collaboration is what I call a side effect. I wasn't expecting the camaraderie, the excitement, and the collaboration that [3D design software] has been able to provide for our team. It's still unbelievable to me.*

By educating designers in both the practical and theoretical aspects of virtual technologies for personal development, Participant DP01 believes it motivates designers to embrace the technology. Participant DP01 states, *"Having that future vision, for them to be a part of that, has really improved their morale and given them a huge confidence boost."*

In addition, a few participants mentioned that new career paths are motivating. For example, Participant DP02 chose to learn 3D design tools to explore potential opportunities in other creative industries. Participant DP02 states,

> *This could be another potential avenue of not just the apparel industry, but maybe even the movie industry in creating products. It opened the door to realise this could be an avenue that I'm not just siloed in one industry and support other industries.*

Personal values and conviction were also mentioned as a large motivation to learn 3D design tools. Participant DP014 decided to leave a traditional fashion design role at a highly regarded fashion house to pursue a role as a 3D designer. Participant DP014 states, *"I gave up my traditional form of art of creation because I saw an opportunity to save the industry. To create a positive impact to make people think before they do… I want to create awareness."*

Participant DP06 also discussed a desire to create a positive impact, as there are many negative practices within the industry. The inefficiencies within the participant's previous organisation caused great frustration. Knowing 3D design tools could create a more efficient way of working and growing impatient with the rate at which the company was digitising, the participant sought other employment. Additionally, personal, and professional values of environmental sustainability did not align with the organisation. Participant DP06 explains,

> *I was also feeling a bit depressed at the targets every year increasing at how much product we had to create, and create, and create. It was just not really fulfilling anymore to be in that side of the industry.*

Participant DP06 suggests using sustainable materials is one way a designer can make a difference; however, the cost of the material is challenging. Participant DP06 states, *"I didn't necessarily have the last say when it came to what materials we used because the merchandisers obviously had targets to reach in terms of margins."* This motivated the participant to learn 3D design tools to be a responsible designer. Some designers did mention feeling unmotivated to learn 3D design tools. Participant DP06 mentioned that creating difficult styles and making them visually appealing is challenging, which demotivates the participant. Moreover, the extra work required, as well as keeping up with software updates, can be overwhelming, challenging, and frustrating. Interestingly, at a previous employer, Participant DP011 shared that some of the designers felt unmotivated mainly because they did not identify as being ‘tech savvy’. Participant DP011 explained, *“It would be a huge undertaking for them to learn a new method to do something that they've been doing for some time.”*

In addition, all participants in Group 2 highly agree that their companies support them in learning or improving their skills in 3D design software by providing a variety of assigned and optional training and workshops. At Participant DP03’s company, each colleague is assigned training hours and eight hours for further training. To fully benefit from the investment of 3D design software, participants mention their employers understand the importance of also investing in and supporting their designers.

Interestingly, many participants highlight the need for managers and upper management to undergo further training, as they feel that managers have a lack of understanding, resulting in unrealistic expectations and goals. Participant CMD04 states,

> *I talk to managers who don’t have an understanding at all about this technology. They had ideas, which were really crazy. They don’t know how it works, and then they ask us to do things which are not possible or efficient...*

As discussed previously with Group 1: Consultants, Managers, and Directors, these participants' roles and responsibilities often do not allow time for training. As a manager, Participant CMD02 explains that *only* designers are provided training. During the COVID-19 pandemic lockdown, Participant CMD02 created a digital collection in their own time to gain understanding.

6.8 3D design technologies bring many challenges

Most participants’ personal experiences with 3D design technologies were highly positive. Needless to say, there were many challenges as well. In this section, the diverse set of challenges participants encouraged are grouped in the following five themes:

- Change management– change in mindset and overcoming resistance
- IT issues create limitations of 3D design technology
- Establishing a realistic time frame for implementation– especially at the start

- Learning to interpret 3D digital prototypes and when to use them
- Digital twin modelling is difficult to achieve

6.8.1 Change management– change in mindset and overcoming resistance

Several participants in Group 1: Consultants, Managers, and Directors mentioned changing mindsets and overcoming resistance towards 3D design technology were major challenges– specifically regarding designers and technical teams. In addition, some participants found resistance when trying to onboard brands and retailers to replace physical samples with 3D virtual prototypes during the decision-making process. Participant CMD02 specifically mentions ‘older buyers’ demanding physical samples, and states,

> *For manufacturers we are bound by our customers…They’re $20-30 million customers, and I have to follow. It’s a service expectant. I don’t have the luxury to exit all these customers and be with no orders.*

Additionally, Participant CMD03 reflects on the resistances to technological change, noting, *“As with any technology, it's always seen as something changing the way you work. As people or creatures of habit, they don't like it…”* The participant shared that before Adobe's Photoshop and Illustrator, designers who were used to hand sketching resisted the software, which have become industry standards. Participant CMD03’s adds, *“I feel that unless it's mandated, they're not really going all in.”*

Moreover, balancing staff training with day-to-day tasks is challenging, as noted by Participant CMD03. Some stakeholders simply do not wish to learn or are unable to. Participants have found that training and learning requires a considerable amount of time and must be factored in during the planning stage.

6.8.2 IT issues limit 3D design technology capabilities

3D virtual design tools have advanced significantly for the apparel sector; however, some participants feel there is still a great need for further development in high technologies and general technological development to achieve the full benefit. Persistent IT issues such as slow hardware, the need for faster bandwidth, and the challenge of managing oversized files consistently cited limitations among participants. For instance, Participant DP01 shares that only 50% of their styles are digitised due to lack of bandwidth and resources constraints. Furthermore, simulating certain styles requires a considerable amount of time. Participant CMD08 states,

> *We do a lot of padded jackets and when using the puffy effect, it's really slow. I find that quite frustrating, especially if it stops halfway through and doesn't want to go any further. You want to almost hit the machine chugging as it's struggling to go uphill.*

Many participants also mention the lack of interoperability between systems and processes. For example, importing and exporting between 2D CAD software and 3D design software results in inaccurate patterns. In addition, a lack of connectivity results in twice the amount of work – especially for designers. Participant DP06 explains,

> *Not only do designers need to put in extra time to learn this brand-new software, but they're also having to re-input all the work they're already putting into the 3D file. For example, where the stitch is going, which kind of materials to use, and all of that information. Then it's not really going anywhere yet.*

In this instance, some participants raised the need for a Product Life Cycle Management (PLM) solution to connect and embed their 3D digital assets in one platform. A connected PLM system would greatly reduce re-entering data manually across systems; however, this is another piece of software in need of further development.

Moreover, many participants have encountered unexpected challenges requiring additional processes and virtual solutions to fully leverage 3D design software. Participant CMD015 emphasises that the expectation of the software to "*just load and get going"* is simply not true. Furthermore, obtaining a variety of needed digital assets, such as fabrics and materials, to create 3D virtual garments poses a significant barrier. For example, Participant CM015 elaborates that brands often manage hundreds and even thousands of fabric types, which need to be properly digitised or categorised properly to be utilised in the 3D design software. However, the fabric digitalisation process can be costly and time-consuming. Participant CMD015 states, *"It was about 300 bucks a pop, and it took a few hours to do so."*

Additionally, other participants mention digital components such as avatars and digital fabric need further development as there are ‘inaccuracies’.

Interestingly, Participant CMD013 feels that marketing has led to unrealistic expectations of technology, and states, *“There's a lot of fluff about what these technologies will do. Marketing is way outstripped by the reality of what the tech will do.”* In addition, cost and accessibility are mentioned as some of the main barriers in the diffusion of 3D design software. Participant CMD013 does not consider 3D design software as a worthwhile investment compared to their current 2D design software. They argue that 3D design software is not only ‘priced out’ but also impractical. Participant CMD013 states,

> *I'm less enamoured by the possibilities of 3D. Simply because it doesn't address the needs. It doesn't allow us to understand things in a way that's advantageous. Maybe it plugs a gap, but it isn't assisting us further.*

Participant CMD013 acknowledges that 3D design software offers the advantage of realistic visuals of products. However, Participant CMD013 argues, *“...but it doesn't in any way address the systemic need to understand body to product relationships in a way that means we're getting a better product outcome.”* The participant explains that while 3D design software is useful for adapting styles and modifying design approaches during the initial phases, it has limitations when it comes to fully realising complex product designs in this manner. Participant CMD013 explains,

> *They [designers] might look at it and go, ‘but the tension map’. A tension map is just a visual articulation of the perceived body to product differences represented by a colourway that isn't even grounded in a suitable understanding of the ease of variants across the body. The product isn't even hung on the body that represents how a product fits the body.*

This highlights a need for further research and development of 3D design software and a deeper understanding of theory in the relationship between pattern construction and the body. The technicalities of developing and engineering 3D design technology such as 3D scanning technology and software is beyond the scope of this study. Nevertheless, the challenges software developers and researchers are faced with are highly important to acknowledge. Technological development – or lack thereof – can directly impact stakeholders, processes, and final products. As a technology developer, Participant CMD06 explains,

> *We're often having to make trade-offs between the performance, the quality, and the ease of use. Obviously, we want all of that to be as good as possible, but sometimes you have to balance things against each other.*

The large amount of capital required to invest in high-tech solutions is also mentioned as a challenge. Participant CMD015 explains that software vendors focusing on apparel/garments are relatively small compared to the software vendors in other industries, such as Siemens. These companies have multiple 3D modelling software, but not for soft goods. Because there are many subtleties of cloth in which are often difficult to model virtually, Participant CMD015 states, *"…They shun flexible materials since it's hard to model, whereas a piece of steel is rigid, and it bends a certain way…"* In Participant CMD05's opinion, 3D modelling for apparel/garments is 'pretty good' but also 'a bit uncanny'*.* However, Participant CMDO5 feels positive and states, *"It's heading in the right direction. To me that's the limitation, but it's an R&D problem. None of those limitations are insurmountable."*

6.8.3 Establishing realistic time frame for implementation– specifically at the start

Many participants explain there are many benefits of 3D design technologies – *once implemented*. However, the 'in-between' phase from the initial time to full implementation requires a considerable amount of time which is often underestimated. These initial tasks includes:

- Undertaking training in relevant 3D design technologies alongside day-to-day responsibilities.
- Planning and implementing new processes, which requires redeveloping workflows and adjusting calendars to accommodate these changes.
- Overcoming old mindsets and managing resistance to change.
- Creating and building digital asset libraries, such as fabric, basic blocks, trims, etc.

In addition, traditionally, design teams and technical teams rarely communicate on a regular basis. Participant DP03 encountered several communication issues between teams at the start. Participant DP03 explains,

> *I think when you're introducing something to the workflow with people that don't usually operate together, because it impacts essentially everybody in the workflow, it can definitely cause some issues there and be a little bit complicated.*

In contrast, Participant DP03 feels 3D virtual prototypes could result in discouraging communication as digital asset libraries are accessible to both teams. Participant DP03 explains that some companies have 3D portals where all information about a product is accessible (e.g. fit charts, .dxf files). Participant DP03 explains, *"So in that sense, anyone can sort of delve in and get the information needed without necessarily having to talk to someone else and to get the information."* Furthermore, participants emphasise the importance of not rushing the process. CMD010 explains, "*It's going to take longer to do than if you have standards, governance, and structure."* This includes creating a strong digital asset library, which requires a significant time investment, but proves highly worthwhile. Moreover, once digital versions are created, they can be reused unlike a physical garment. Participant DP010 explains,

> *A physical sample can be used maybe 2 or 3 times. In 10 years' time, you won't be able to show it to someone else. It will have no use. With a 3D sample, you can change silhouettes, define shapes, or change colours. You can continuously use it...it's a long process. It might not be a linear process, but a circular process because these are digital products. You can use it over and over.*

Furthermore, a digital asset library provides a basic pattern for designers to begin garment development without needing to draft a new pattern from scratch. This is similar to having a physical repository of physical block patterns that brands maintain. Despite the initial learning curve, participants are optimistic and note that users become more proficient with the software over time.

6.8.4 Learning to interpret 3D virtual prototypes and when to use them

Interestingly, some participants highlight that learning to interpret 3D virtual prototypes and making decisions is challenging for some. Participant DP03 makes the point that signing off on 3D virtual prototypes can be more challenging for designers who are used to traditional methods. As a result, these designers tend to resort back to their traditional way of working. Participant DP03 shares,

> *When you try to combine a 3D render, but you're printing it out, treating it like a CAD, and not showing it virtually, it kind of weakens the message a little bit. So, we've had a couple of issues with signing off in 3D. I think with new technology, some people are more willing to adapt to change.*

Despite having a high level of expertise and experience in physical product development, which is essential to carry out the process virtually, 3D prototypes can be misleading. For example, Participant CMD04's team carried out a virtual fitting, and the garment appeared to fit. Once the physical sample was made, however, the design did not work. Only after a physical fitting, the team could see the mistake on the virtual avatar. Participant CMD04 states, *"You have to get used to it…You have to learn to see."* In addition, when working with physical models, Participant CMD04 explains there is much insight to be gained by observing how someone might interact with a garment. For example, if a model puts on the garment where the back is intended on the front. Participant CMD04 states, "*An avatar says nothing. It will not act by itself, but only what you tell it to."*

Other participants admit that on some occasions, 3D design software is not the best tool. Regarding management, Participant DP09 explains there is an expectation of designers to utilise the software at all times. However, Participant DP09 states, *"In certain areas of the company that works great, but in other areas it doesn't."* For example, animating and rendering 3D virtual assets to look realistic takes a considerable amount of time. Therefore, it might be quicker to have a physical model and photoshoot. Participant DP08 also suggests waiting until the customer has an idea of what they want before creating a virtual prototype. Participant DP03 explains, "*It's almost better to put something into 3D knowing that you're reducing a sample the customer wants. There's a purpose behind it."* However, Participant DP03 reflected on this response, and argues that it could be useful to help their clients visualise and select designs. The participant witnessed this in a presentation meeting the previous week, and the clients reacted positively to the 3D renders.

Moreover, some designers might argue it is quicker to sketch an idea or to make a quick physical prototype. Participant DP08 currently does not utilise 3D design software, but regularly utilises 2D design software. The participant explains it is easier to make a quarter scale model to check if the pattern pieces work. Participant DP08 states, "*I would imagine there would be similar sort of drawbacks with the 3D software. At the end of the day, you are still looking at it on a 2D screen."* The participant argues the lack of touch and the movement cannot be replaced as fabrics react differently. In addition, colour is highly important for certain garments such as workwear, which is regulated. This raises concerns as colours might differ across monitors. Therefore, the physical method might be more suitable.

6.8.5 Digital twin modelling is difficult to achieve

The topic of digital twin modelling was also raised by many participants as a main challenge. Participant DP07 defines digital twins as creating digital copies of the physical item– a 1:1 comparison. Working virtually has led to a reduction of physical samples; however, many participants acknowledge their 'digital twin' models are not a true 1:1 comparison. Digital twin modelling is difficult to achieve – especially soft goods such as garments. Garments that fit closely to the body such as intimates and swimwear were specifically mentioned as problematic to develop virtually. Avatars need to be 'squishy' and soft like humans instead of stiff and rigid.
Not only do digital twins need to be functionally accurate, the 'realness' or the visualisation also must be convincing, as it could result in lack of trust and rejection of the design during sales presentations. Participant DP015 explains,

> *You can have a great 3D model of a style, but if who you're trying to convince does not believe that it's a good representation of real life, or there's any sort of trust issues there, then it becomes really difficult to get the buy-in from all the partners in a team that really need to believe.*

From a manufacturer's perspective, Participant CMD011's overseas customers still demand physical prototypes before making a purchase order. Participant CMD011 states, "*They don't accept the virtualisation process because they think it's not always the same as the real one."* This might be a result of computer monitors displaying a different colour or texture of the fabric. Interestingly, Participant CMD011 explains that the opposite expectation can occur as well – the virtual garment appears better than the physical. CMD011 states, *"When clients see the virtual, they always think well so it's not true. Maybe I cannot make it as beautiful as that one."* In addition, if the virtual model is used to deceive consumers, this could have negative implications. Participant DP01 states,

> *You can fake a lot of things in 3D if you want to...Others may use it as a bit of trickery. Show something is perfect, and then in real life it doesn't meet those same expectations.*

If consumers find that what they have ordered does not match the 3D prototype, this could lead to a loss of sales and brand loyalty. In addition, Participant DP02 raises the concern that the process of creating customised avatars and accurate body measurements might lead to further body insecurities. Participant DP02 states,

> *The mental stage of this brand is telling me I'm a size large, but I've always bought medium. So how do we connect with the consumer and make sure that the virtual assets are not making them feel uncomfortable.*

Participant DP02 suggests supporting consumers and making them feel comfortable will become even more important. Consumers will need to take part in these conversations.

6.9 Summary of Interview Results

The individual interviews provided a deeper qualitative discussion and understanding of virtualisation within the fashion industry. From a variety of perspectives and skills, it is evident each sector and its stakeholders will have their own sets of challenges and processes to consider regarding virtualisation and digital transformation. In addition, the virtualisation of the product development will require an ecosystem made up of technologies, experts, and processes. There is evidence of organisations successfully undergoing digital transformation and seeing benefits. Traditional processes no longer support consumers' demands and resulted in the fashion industry's pressing issues. In response, virtualisation alongside societal changes can be a solution to these issues. Despite the issues and challenges regarding digital technologies, digital transformation, and virtualisation, the interview participants are highly optimistic. Participant CMD015 states,

> *I think this is a super exciting time. Everybody talks about how they want to change the world, but actually, you're in a field where things are going to change. It's a great future. There will be good times and bad times, but all in all, there's so much to accomplish. We're on the cusp of doing it.*

Many participants stated the interview process was an enjoyable experience as they feel excited about the topic. It was an opportunity to reflect and voice their frustrations, challenges, and successes – in which they do not get to participate regularly.

The following chapters will present three case studies to further explore the findings from the survey and personal interviews, and to observe the phenomenon of virtualisation and relevant digital technologies in their natural environment. Thus far, the survey and personal interviews have informed the case study structure and identified potential companies for the case study research.

Chapter 7: Case Study 1 Report

7.0 Introduction to Chapter 7: Case Study 1

This chapter presents the findings and discussion of Case Study 1. The purpose of this case study is to gain insight into how virtualisation of the product development process is being undertaken in the fashion and apparel/garment industry. Using an interpretivist approach, this is achieved by observing and analysing the research question within the real-world context of a company. Company 1 has successfully completed the initial stage of adoption and implementation of 3D design software, resulting in a profound impact on the way the company conducts business. Case study 1 explores the challenges the company has overcome regarding digital transformation. Furthermore, the study provides an overview of the outcomes and practicalities of implementation of digital technologies to support findings for the PhD research question. This chapter explores the following:

- About Company 1
- Product Development Process
- Journey to digital transformation
- Impact of COVID-19
- A digital 'toolbox'
- Impact of 3D design software
- Attitudes towards 3D design software
- Challenges and limitations of virtualisation and digital technologies
- Case Study 1 findings and discussion

The next section introduces Company 1, providing context for this chapter's discussion.

7.1 About Company 1

Company 1 is an apparel/garment manufacturer located in Denmark, offering a variety of garment design and manufacturing services. The mid to large-sized global company employs 700 employees across offices and factories in Denmark, Ukraine, Türkiye, and Lithuania (Company Website, 2022). Founded in 1968 as a supplier of jersey-style knits for various European brands, Company 1 as a family-owned and operated business, with an emphasis of family values, evident as the head office operates from the original production facility.

Company 1 operates as a full production package (FPP) manufacturer, providing design, product development, and garment production for private labels (See Figure 7.1). As an apparel/garment manufacturer, the main objective is to simplify the manufacturing process for the customer and to offer the best product and price by optimising workflows and processes. Company 1 offers trend research and design services for brands/retailers, a common service among garment manufacturers.

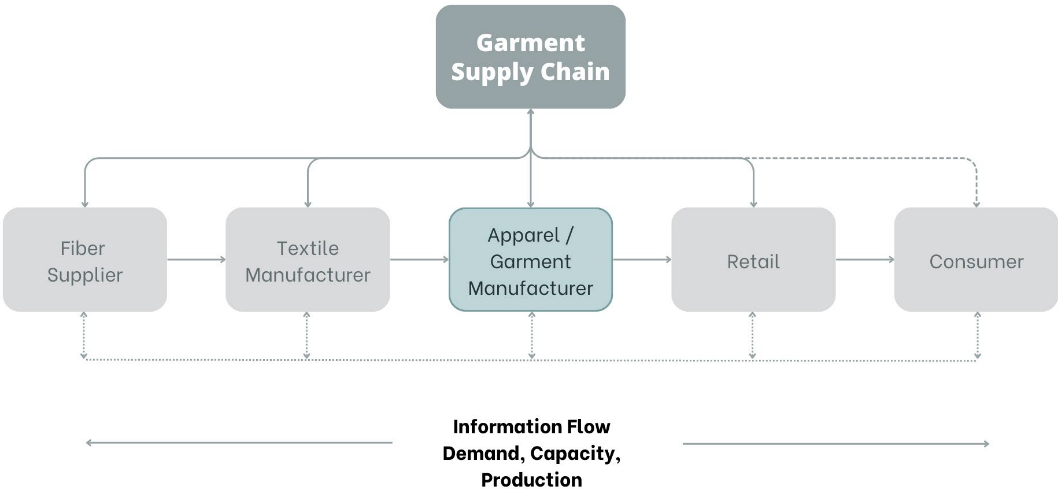


Figure 7.1 Mapping Company 1 along the supply chain
Adapted from Coughlin, Rubin, and Darga (2001), p.81.

7.1.1 Sportsmanship, unity, and equality

Company 1 is located in a region renowned for Denmark's textile industry and for training some of the country's top athletes. The respect for sport and values of sportsmanship are deeply shared among participants. It was evident each participant considered their colleagues as valued teammates, with office language including *"be sure to play ball"* to foster collaboration. Participants emphasised feeling part of a team and a community. Participant CS101 states, *"We don't have any bosses…We try to work as a team and work closely. There's not many businesses built up like this."* Equality and unity core principles throughout the office. Each department operates within a single, large open space, originally a sewing and production room.

This intentional setup communicates that every role is valued equally, fostering communication and teamwork.

7.1.2 A partner – not a supplier

Company 1 meticulously selects the ‘right’ partnerships, focusing on those who share the same value system and mindset to innovate and collaborate effectively. Participant CS101 states, *“We would prefer not to be looked at as a supplier, but as a business partner with close relations and work close together.”* Establishing partnerships involves all stakeholders, including lawyers, bankers, and IT teams. Participant CS101 states, *“If they’re a partner, then you also give a little bit more of yourself. Run this extra mile to help.”*

Alignment of values is crucial for Company 1, and they are prepared to decline partnerships where values do not align. Participant CS108 states, *“If they’re not wanting to work our way, then we can’t do business.”* There is an expectation of equality and collaboration, rejecting the traditional power dynamic of brands over their suppliers. This way of operating has proven an effective business strategy, contributing to an improvement in garment quality. If the Company manages to succeed in building partnerships, Success in building these partnerships is seen as crucial for Company 1's business to develop and sustain. Participant CS101 states,

> *It's not the goal to get 100 customers, but maybe 10 to 15 partners…a partner relationship brings in more value through a more stable turn over…It's better to run a little bit every day instead of losing one month and then less another.*

As a family-owned and operated business, Company 1 is committed to preserving its legacy. Participant CS101 states, “*We are not focused on profit in the short term, but in the long term. Our investments and decisions are not to make profit tomorrow, but the coming years.”*

7.1.3 Social and Environmental Responsibility

The importance of aligning values extends beyond technology to include ethical and social responsibility. Prioritising the reduction of social and environmental impact is a high priority. To foster positive social impact, Company 1 invests in educational opportunities for the women in their factories in Bangladesh. It is important to

Company 1 participants to *“not only talk the talk, but walk the talk.”* Participant CS101 states,

> *We actually try to make a difference and do things a little bit different because that's the only way we can bring value into the whole company. We continue to look for more ways…I also try to bring change in the industry to raise the level of what is acceptable and what is not acceptable in the way that the garments are produced.*

Participants at Company 1 avoid using the term ‘sustainable’ due to its ambiguous meaning and does not reflect the organisation. The term is perceived as a buzzword that lacks clarity and is subjective depending on the company and the context. Instead, participants prefer to emphasise 'responsibility'. Participant CS110 views sustainability as the ongoing evolution that prompts the question, *“What is today, and where are we going?”* Therefore, the term 'transparency' describes what Company 1 aims to achieve regarding environmental sustainability. Participant CS101 states,

> *When you look at all the manufacturers, there's still too many who don't care about what their use of water is or electricity. There are too many focused on making the most profit possible instead of looking into the responsibilities we have as [as manufacturers].*

The participants share strong values of circularity and reducing waste within all areas of the business. This is as simple as feeding leftovers from lunch to an employee's chickens to reduce food wastage. The circle continues with fresh eggs shared with the office. Other initiatives include its own brand, which has conducted extensive research in creating natural garments with the least amount of environmental and social impact. Moreover, the company employs an in-house environmental sustainability researcher to stay updated on EU legislation and textile production and to begin calculating its carbon footprint. Participant CS1011 states,

> *I think we are pretty much ahead of the rules. We've started before many of our competitors have at least as far as we know…I think this will impact the textile industry in a lot of ways. More specifically, I think it's going to be a licence to operate in the future.*

The company is proactive in ensuring their business operations are held responsibly and ethically accountable. Company 1 has integrated several certifications, including Global Organic Textiles Standard (GOTs) certification.

7.2 Journey to digital transformation

When discussing digital transformation, Company 1 defines their digital initiative as the process of utilising 3D design software to replace physical garment prototyping and development. At Company 1 there is an understanding and willingness to invest in high technologies to reduce resources and create optimal processes. All participants were unanimous in agreeing that digital transformation is worthwhile for the industry. Moreover, investing in digital technologies and new processes is viewed as a competitive advantage. Participant CS111 states, *"At some point technology is going to take over, and it's already taking over. I think it's going to be make or break whether or not you invest and learn."*

Despite Company 1's success in the implementation of 3D design technology, there were many challenges the company faced prior to. Participant CS101 states, *"So, it sounds so easy, but it has not been easy. You also have to ask, are you doing the right thing?"* Company 1's decision to undergo digital transformation was the outcome to a series of internal challenges. Participant CS101 shares,

> *We were not able to earn money working like all the others [manufacturers]. We had two options. One, close down and say that is that, or we can say how can we change this? How can we change our mindsets?*

Ethical issues were found in their previous production facilities and local management teams in Asia. This placed upper management in a difficult situation, resulting in staff layoffs. Participant CS101 states, "*That's also when we started looking into CSR and general responsibility, too."* Company 1 pulled business operations out of those regions and began planning to restructure the company.

Beginning with a focus on their 50+ years of experience and knowledge in garment manufacturing, the team worked backwards to identify which technology to invest in, where to integrate it, and what future development plans to pursue for the chosen technology. This led to the discovery of 3D design software in 2017. Participant

CS105 states, *"...I think they just saw that it made sense. There was something we could do better with 3D, and then they started looking into it from the design department."* As a result, the technology has reshaped their product development process. In hindsight Participant CS101 states,

> *There have been many times where I was nervous that, yeah, we're probably wrong. We're not finished yet, but I'm sure that we are on the right track. On a daily basis we're making adjustments. We are very much aware that we don't know everything.*

Several participants explain there is an understanding that 3D design software is not the end of the investment – nor the only virtual solution. Participant CS101 states,

> *We have to continue and try to adapt where it may make sense with these new technologies… First starting with 3D and looking at the whole road until we have delivered finished garments in the box. Actually, we also have to look into the afterlife…We have a responsibility there as well.*

The company continues to research and invest in solutions they believe will provide the most benefits throughout the garment life cycle.

7.3 Impact of COVID-19

As discussed in the literature and individual interviews, the pandemic accelerated digital transformation, and is considered a main drive of the adoption of 3D design software for the fashion industry. However, Company 1's interest in digital technologies and transformation began prior to the pandemic. 3D design software proved its usefulness and value during lockdown. As physical garment samples were unable to be sent and received, Company 1 relied on 3D virtual garments. Participant CS101 states,

> *It was one of the ways that has helped us a lot, but we could continue the way we've been working. We just had to do some small changes instead of looking at the samples physically. Then we look at our 3D samples and do the fittings.*

Importantly, the COVID-19 pandemic became a driving force for their brands and retailers to understand and accept 3D virtual garments. Prior to the pandemic, 3D virtual models were a nice ‘add-on’. However, the sales team found in Spring 2020, the start of the pandemic, accelerated interest, and willingness to begin utilising the technology. Participant CS101 states, *“...That was an eye opener to many because they saw we could continue working.”* During the pandemic, brands and retailers saw an increase in ecommerce sales as physical shops were closed. Participant CS101 states, “*So, that was a very big game changer in their understanding that you can work digitally.”*

7.4 A digital 'toolbox'

3D design software is one technology and process needed to support the creation of 3D virtual models or digital twin models. This can be referred to as Digital Product Creation (DPC). Company 1 has a ‘Digital Toolbox’ which consists of digital assets – such as digital libraries and related technologies (See Table 7.1) Company 1 continues to upgrade and add virtual solutions.

Digital Product Creation (DPC) Tools	Description
3D Design Software	Compatible 3D design software to carry out 3D digital prototypes and product development.
Digital Textiles Library	Fabrics are digitised from their 3D design software vendor to create a library housing digital fabric scans.
Digital Garment Block Library	Company 1 has developed its own digital blocks to work from and is considered the most important tool. All seams and block patterns are developed with clients, or clients often have their own with measurement charts. Developing a digital asset library is a complex process. A t-shirt alone can have up to 200 variations.
Avatars	Customised avatars are created for each client based on their size charts for true to scale models. This allows for correct grading of patterns to improve garment fit. Company 1 uses digital avatars to fit garments – no physical models are used.
PLM System	Company 1 and clients work in the same PLM system to access their 3D virtual prototypes and to adjust them in real-time. This will be discussed further in this chapter.
Rendering Software	Rendering software such as Adobe Substance and Blender are used to make the final visualisation to achieve the highest quality and realism.

Table 7.1 Company 1’s DPC Toolbox

7.4.1 Selecting a 3D design software

The design team primarily uses [Software Vendor A] as the main 3D design software. When selecting this software, Company 1 trailed four different software, and selected [Software Vendor A] based on functionality despite [Software Vendor B] having more appealing digital assets, such as avatars and graphics. Participant CS105 explains the competitor will 'always' have something the other does not, but the designers have found [Software Vendor A] to be receptive when asking for improvements or certain features.

If a client uses a different 3D design software, the file is converted to a compatible file. However, the participants believe that [Software Vendor A] is the most compatible with their other software tools during the production stage. However, Participant CS101 states, “*…we are still testing and making sure that [Software Vendor A] is still the best because we want in the long run to have the best software.”*

7.4.2 Digitising Textiles

Currently, Company 1 does not digitise their own materials. The fabrics are sent to [Software Vendor A] to be digitised; however, this process can take weeks. In the meantime, the design team will choose a similar weighted fabric. The team has started developing a digital library of their core fabrics organised by basic and popular textiles. Each fabric used is organised in folders by client.
Fabric digitalisation is its own process and requires a fabric digitiser which analyses and calculates the physical properties. These devices are often expensive, and Company 1 believes it is not critical to invest at the current moment. Company 1 has asked their textile suppliers to consider digitising the fabric at their mills. The textile suppliers were not against the idea, but the financial investment was too great.

7.4.3 Digital Twin Modelling

One main responsibility of the design team is to render or animate the 3D virtual garments to be presented to clients. However, the design team emphasise that 3D virtual garments are not only for the 'visualisation', but must be a digital twin or true representation of the physical garment. Both must be achieved to fully benefit from the technology, and to begin building an infrastructure to support future technologies.

Participant CS104 acknowledges that creating 3D virtual garments still requires a long process and involves many people; therefore, the team is mindful of selecting styles. Participant CS104 adds, *"...We are trying not to waste time creating 3D designs just for the fun of it. It needs to have a purpose."*

Some of the participants believe that the general industry is using 3D design software for visualisation only, and not necessarily functionality. As a result, the technology is not used to its full capability. For example, at Participant CS104's previous employer, the company was using 3D virtual garments for sales meetings. In response, Participant CS105 expressed scepticism about the value of such usage, stating "*Then it's not implemented. It's more like taking a new tool in and adding that to the flow."* All three designers agreed.

At Company 1, undertaking digital transformation involves continuously developing strategies and investing in technologies to achieve true end-to-end digital product creation. The company aims to minimise physical samples and to carry out decision-making digitally across all feasible areas.

7.4.4 Limitations of digital tools

Furthermore, some participants highlighted the limitations of digital tools that support 3D design software. For example, Participant CS105 mentions that avatars need further development, as they are not a true digital twin of a physical body. However, software vendors are currently developing 'soft body' avatars. Moreover, a few participants discuss limitations of PLM software. Company 1 is searching for a new PLM, as there is no connectivity and integration between their current system and 3D design software. Moreover, to view the 3D virtual garment in the PLM system, the additional step to click the link slows down the workflow, as users must continue open and search tabs that contain the needed 3D images.

Participant CS1010 highlights the issue and explains that the current PLM solutions include images and sound files similar to Adobe files in terms of which information they hold. However, the files do not contain the garment information. The are three main file types:

1. The minimal file – which consists of just a shape.
2. Style file – shape, loose fit, fabric swatch.

3. Garment files – production ready file which may mean that the garment has already been produced.

As a manufacturer, PLM software will need to include different functions compared to a brand. Participant CS1010's explains that many organisations are focusing on finding a PLM platform that supports and integrates all the virtual solutions in one place. However, Participant CS1010 stresses the importance of good data and data asset management (DAM) files. In Participant CS1010's opinion, the software provider or type of software is not as important as:

1) What data do they hold?
2) How is data stored?
3) Who manages the data?

7.5 Impact of 3D design software

Company 1 is an example of an organisation that has successfully implemented 3D design software within their workflow. The technology and processes have significantly impacted their product development process by reducing time and resources. As seen below in (Figure 7.2), the original garment sampling process could require up to +28 Days.

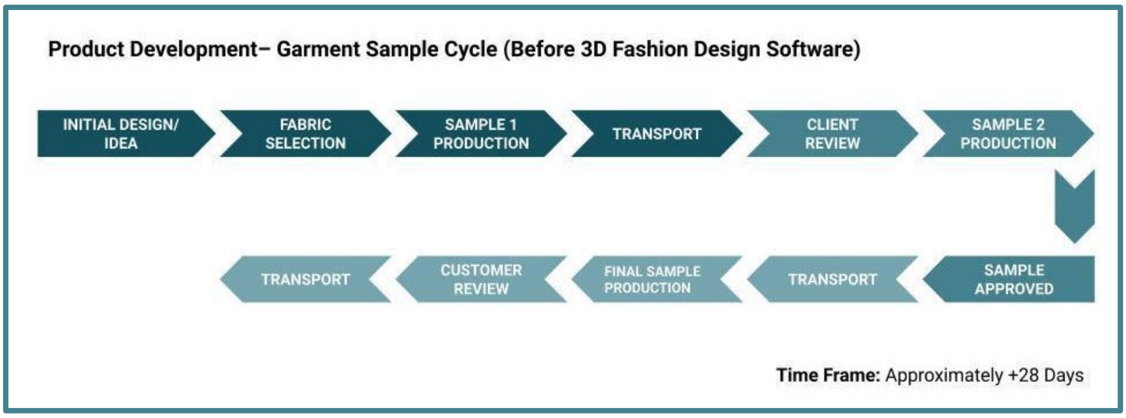


Figure 7.2 Garment Sampling Cycle Before 3D Design Software
Adapted from Company 1 Literature (2022)

By utilising 3D design software, Company 1 significantly reduced the garment sampling cycle from over +28 days to a span of few hours up to 2 days (See Figure 7.3)

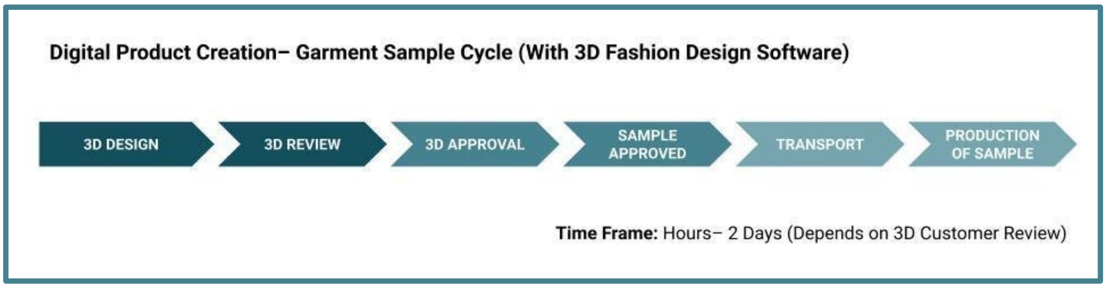


Figure 7.3 Garment Sampling Cycle With 3D Design Software
Adapted from Company 1 Literature (2022)

Company 1 has found many benefits in utilising 3D design software – including cost savings in the number of samples and courier costs. Participant CS101 states, *"You don't get samples for free. In fact, they are very expensive to do."* Roughly the costs in courier and physical prototypes can amount to approximately USD $100,000 alone. The traditional workflow required samples for every minor change to a design, and could take up to one month, consisting of two to three shipments of samples before arriving at the final prototype. Participant CS101 states, "*You need to produce 10 or 15–20 samples before you get one that ends in production."*

An objection to 3D design software is that the start-up and maintenance costs are considered a high investment risk. However, Company 1 has found the return of investment is far greater. When exploring 3D design software, Participant CS101 explained that both software vendors claimed the use of the software would lead to a cost reduction of 50%. Participant CS101 carried out the calculation along with Company 1's figures and found roughly around 20% reduction would allow Company 1 to break even, including expenses for the software and training costs. The actual return surpassed management's expectations. Participant CS101 states, *"I believe we have a cost savings of maybe 90% or even more. It's more than paid for itself. Done many times…"* Participant CS101 believes the value of 3D design software is invaluable, and the new 3D design process and workflow has enabled Company 1 to carry out business in a way that was not possible before. Participant CS101 states,

> *We are able to be much more flexible in the way we're working and give our customers much better service. If they have some changes in ideas, we can model it on the fly… I cannot tell you the exact figure, but it's good because I can look at the figures over the last 2–*

> *3 years. We have increased our turnover and profit by working like this. So, it's been quite a good investment.*

7.5.1 Product Development Process

At Company 1, product selection, design research, and product development are carried out digitally, involving screenshots of current design details, styles, and trends. The process begins at the head office where clients collaborate and Company 1, either virtually or in-person. The workflow is as follows:

1. The Design and Development Team receives orders from the sales team or directly from the clients.
2. The Patternmaking Team is contacted to create the patterns for the orders.
3. Depending on the customer, a presentation is prepared that includes interactive 3D virtual garments and/or animations.
4. The Patternmaking Team calculates the cost and consults with the Design Team and Sales to obtain client approval.
5. Once the final prototype is approved, it proceeds to production.

Product development occurs across Denmark and Lithuania. The Design and Development Team in Denmark works with the Patternmaking Teams based in Lithuania to create tech packs and the production samples for the Production Team. Production is carried out in Türkiye, Ukraine, and Bangladesh (See Appendices F for further details of each team's responsibilities).

Company 1 utilises 3D design software to develop initial physical samples. Therefore, there is a limit in the number of physical samples included in the pricing for customers. Each team has a basic understanding of 3D design software, and the 3D digital garment is used throughout the teams (See Figure 7.2). However, it is important to highlight that a physical garment sample is still required for the Production Team.

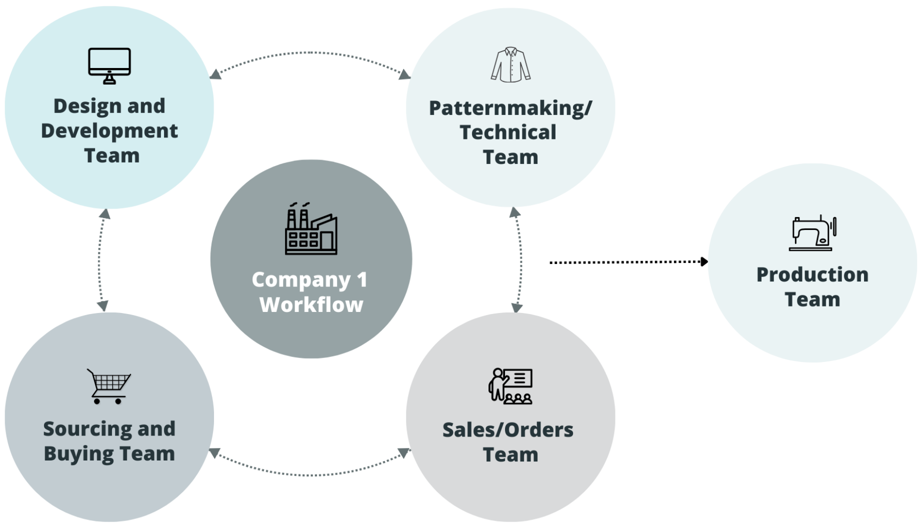


Figure 7.4 Company 1 Team Workflow
Adapted from Company 1 Literature (2022).

It is important to highlight Figure 7.4 as it depicts the continuous flow of communication between teams. No team is siloed, and there is no hierarchical power structure. During the visit to the head office, this dynamic was clearly visible, with teams actively engaged in knowledge exchange as a team to deliver the best product and services possible for their clients.

7.5.2 Training and Recruitment

The importance of employee development and the recruitment of new talent was highlighted as a result of 3D design technology. Participant CS101 states, "*We're doing a lot of training and trying to get everyone to have a better understanding of the use of IT in all the ways we work."* Each employee is assessed on their IT skills and are assigned individual development plans to support growth. Designers undergo training in a course provided by the software vendor, and regular training sessions are carried out. Participant CS101 describes it as a *"new language to learn".*

When discussing the topic of finding new talent and skills, Participant CS101 believes this will require recruiting global talent as there is a lack of skills within Denmark – especially technical skills. To address the current skills gap, Company 1 recruits students from local and surrounding universities. Participant CS101 believes the talent will come from students and is one of the main ways to stay competitive.

Participant CS101 states, *“We will probably not find the skills at other companies because they have too many of them with the same [traditional] mindsets…Young designers, they can see a lot more possibilities.”* The company also relies on word of mouth and social media such as LinkedIn. Participant CS101 states, “*I think using LinkedIn and other digital media to tell stories about [Company 1] is an important part in this process.”* The company offers internships alongside students' studies.

As new technology is introduced, it is encouraged for the different teams to take part in conversations and observation around the technology. This is a benefit of the teams working in an open space to avoid silos and create awareness of transformation the Company is undergoing. Participant CS105 states, *“Some of the women have been working here for 20 or 25 years. They don't know what we are actually doing with the 3D, but they can pass our screens and see that we are working with avatars.”*

7.5.3 Next focus area– production

The current advice to companies for undergoing digital transformation in regard to creating virtual assets, is to start with one product category or area of the business then transition into other areas. Company 1 began with the design team at the head office, and within five years, the transformation has filtered through to their patternmaking/technical design teams. The next phase in Company 1's digital transformation plan is production. When asked what this might look like for production, Participant CS105 envisions a future with a limited number of samples and an automated system to determine fabric consumption for a design.

Company 1 has already made significant reductions in the number of physical prototypes through the use of 3D design software. However, the aim is not to eliminate the physical prototype. At least one physical prototype is needed for the production stage, and to ‘feel’ the sample to ensure quality. Participant CS107 states, *“No matter if it's approved in 3D, we still need to make one because production still needs the sealed sample to see how it looks. They need to see the seams, the stretchability.”*

Participant CS105 believes 3D virtual prototypes are not a true digital twin of the physical garment, and states, “*In 3D you can add 3x more gathers if you want, and it* *will just do it, but is it possible to sew it together?"* Occasionally, the virtual prototype looks correct, but the physical sample is incorrect, as the software is not capable to account for garment shrinkage during sewing or the stretch of the fabric. In addition, part of the role of the patternmaking/technical team is to configure the order of operations of assembling the garment. Written out sewing descriptions must be included with the physical sample for production. Eventually, Participant CS105 believes this information can come from the 3D virtual prototype, as some of the information is within the digital file. However, the technology does not have the capabilities yet to predict patterns or generate instructions. Participant CS105 explains, *"I mean some difficult styles might need deeper explanation because in 3D you have a stitch, but what is behind the stitch? How are the details put together? You don't have all these details."*

The participants also highlight the importance of building trust in the software before fully believing in the3D virtual prototype. Participant CS107 states, *"We need to believe, and our sewing sample room needs to believe in 3D. We need to trust 3D."* The team verifies the final approved sample, known as the sealed sample, to ensure the virtual prototype matches the physical garment. The team has found it easier to trust virtual prototypes of simple styles. However, more complicated styles, such as those with pleats, can be more challenging. Participant CS107 states, *"We have to think about how our constructors can sew in 3D, how to cut, how to sew. Here we have challenges.*" Participant CS105 experienced similar challenges in Türkiye, when working with the patternmaking team. Participant CS105 explains,

> *They know how to make a pleat on the pattern, but when they try to sew it, is it this point to this point, or that point? I think the fact they need to sew it together makes them aware of the quality of the pattern because it's very important for the person who is sewing it together – quality check of their own patterns.*

If there is doubt around the virtual prototype, a sample will be made to ensure quality. Participant CS105 believes that 3D design software can assist in understanding how the garment instructions will need to be prepared for the production team, and states, *"Sometimes we try to do it as the line would be. That's the great thing about the sample being sewed at the factory."*

Eventually, Participant CS105 envisions the 3D virtual prototype to be used on the production floor to replace the physical garment sample. The production team could view the 3D virtual garment on an interactive screen to examine how the garment is to be assembled. However, the expertise of a garment technologist to understand what can be created physically would still be a requirement. Participant CS105 states, *“This is where there is some translation needed at the moment. I still feel there must be somebody technical to give this translation, but I'm sure at some point this will be automated as well.”* Participant CS107 feels highly doubtful this will happen anytime soon, but states,

> *I hope it will be possible to see it as the technology is moving forward. For now, in my opinion, 3D is more for designers and for the garment technologist, but I hope, and I believe, it will be possible in the future.*

In addition, Participant CS105 highlights considering cultural factors when implementing new processes. It is essential to approach operations in a way that makes sense and best for the workers. For example, Participant CS105 has observed systematic mentality in Lithuania, where processes are often viewed in black and white. In contrast, attitudes in Türkiye tend to be more flexible, with improvisation being common. Participant CS105 explains the cultural factors will need to be considered and approached with empathy when deciding to implement technology at the production stage.

There are a number of challenges in digitisation apparel/garment production, particularly due to its traditional reliance on manual labour. For example, the lack of IT hardware and the investment needed to upgrade technology must also be considered. Participant CS105 states, “*The files we are giving them are printed out in black and white on a quite old printer as well. So, we also need to be aware of how the reality looks where we manufacture.”* The technology used in production includes industrial machinery, such as cutters and sewing machines, aimed at increasing optimization. As a result, many production teams may possess only basic skills in Microsoft Office and lack digital proficiency, as these skills are not typically crucial to their roles. Moreover, a significant amount of garment factory workers are illiterate and often do not speak English. In Bangladesh, factories often use colour codes or symbols to convey instructions. Staff would require training, which could result in fear of the unfamiliarity of working with computers. These challenges highlight the importance of recognising that technology adoption may not be suitable or practical in garment factories compared to the Denmark office. Participant CS105 believes it is crucial to meet their needs and involve them in discussions about adopting new technologies.

7.5.4 The Sales Team

The implementation of 3D design software has directly impacted the sales team through the redevelopment of sales strategies and the onboarding of customers. The team now focuses on educating potential and existing clients about the benefits of 3D design technology. Given that many of Company 1's clients have been with the company for 25 years, Company 1 feels a responsibility to support these clients in understanding the practicalities of implementing virtual technologies. Moreover, the company is open to sharing their knowledge as it promotes a more optimal way of working for both parties. Clients in the initial stages of integrating 3D design technology are provided 3D virtual models or assisted in building their 3D libraries. Each client requires a different approach, and there is no standard method for onboarding clients. The team customises each sales pitch and demonstration to help clients visualise how the technology can be implemented into their workflows. Participant CS108 and Participant CS109 share two instances where this approach successfully led clients to trust creating garments virtually:

- Example 1: A purchasing manager was curious about Company 1’s process in utilising 3D design software. The client had unused funds from the budget to pilot the process. A few designs were created in the 3D design software, and the client made purchasing decisions solely on the 3D digital garment. The final garment surpassed the client’s expectations.
- Example 2: After learning that the physical samples for an important sales meeting would not arrive on time, a major retailer contacted Company 1. The design team quickly created the 3D virtual garments, which were successfully presented at the sales meeting.

For both examples, these instances convinced the clients to trust the process of creating 3D virtual garments. In addition, the sales team has found that companies approaching Company 1 have shown great interest in their 3D virtual capabilities. However, Participant CS108 and CS109 highlight that there might be resistance from different departments within the same company regarding the acceptance of the virtual model. For example, convincing buyers to accept a 3D virtual model as opposed to showcasing physical samples can be challenging. The team has also observed that companies operating B2B are often not interested in virtual garments because they struggle to convince their retailers to purchase based on the virtual garment alone.

7.5.5 The physical office

The physical showroom in the main office is being redesigned to reflect and communicate Company 1's initiatives to utilise virtual technologies for a more efficient, effective, and responsible approach to traditional garment manufacturing. Currently, the showroom contains garment racks of physical samples, and dress mannequins showcasing garment styles. Participant CS105 states, *"If you go into the showroom, you can't really see that we are a 3D company. So, we are in the process of changing it."* The company has invested in interactive monitors to display the products, replacing the physical garments. The textile header samples will be left on the racks for the client to feel the fabric. Showcasing the product virtually aims to communicate to clients that Company 1 no longer supports traditional industry practice.

7.6 Attitudes towards 3D fashion design software

During the onsite visit, focus groups were conducted with teams whose roles have been directly impacted by 3D design technology. The teams included the Design Team (x3 participants) and Patternmaking/ Technical Design Team (x3 participants). The discussion with the Patternmaking/ Technical Design Team was held over video conference with two members joining from Lithuania and the lead designer from the main office. This section discusses how the participants view 3D design technology.

7.6.1 Design Team

Overall, the Design Team felt highly positive towards 3D design software and have seen tangible benefits. The benefits mentioned are as follows:

- Reduces shipping and receiving of physical samples between teams.
- Reduces workload, time, and expenses in the development and fitting phase.
- Creates value by allowing a better service offering for customers.
- Enables faster communication between teams across different offices.
- Speeds up decision making of garment styles between design teams, sales, and clients.
- Allows detailed examination of full garments by zooming in or rotating the virtual garment.
- Enables clear communication of true design intent between designer and pattern maker, thus reducing misunderstandings.
- Removes doubt of a 2D technical drawings, instilling confidence, trust, and assurance in the style before physical sampling.

The main benefit discussed in regard to 3D design software is the improvement of communication. Participant CS103 comments that communication is *"...straightforward, shorter, and easier with the 3D."* Participant CS105 adds 3D design software as a strong communication tool for interpreting designers' ideas. Participant CS105 explains,

> *We had 6 designers, and everybody's flat drawings and lines were different. So, you need to get to know who is drawing it to understand it, and I knew all the designers. I had the chance to say to the sewers or the pattern makers, this is what she means, or you see it like this, but I'm pretty sure she means like that. With 3D it's just up front. There's nothing to be in doubt about.*

The participants emphasised that communication becomes even more important between the teams, as the roles are converging. For instance, the design team can also alter the digital pattern to communicate the desired outcome or make amendments suggested by the client instead of relying on the patternmaking team. Participant CS105 explains,

> *When I get a 3D style, we might not agree here, or maybe I was not clear on where I wanted the cut line. You can easily go in, make the cut line yourself, and say this is what I meant…there are a lot of feelings in the explanations.*

The team must ensure to leave notes or update the patternmaking team on any edits that were made. In addition, the participants have found that 3D design software provides an easier way to communicate to their clients what styles will work – or *not*. Participant CS105 explains,

> *Sometimes we have several designers who previously have asked to make a design in 100% cotton. Then we have to tell them it's not going to drape nicely. But they say just try to make a sample anyway. These kinds of things you can see or feel quite instantly in 3D.*

The virtual model allows the designer to see details that might not be visible with a physical prototype. For example, turning the transparency down on the outer layer of the virtual garment allows the design team to see design details, volume, and shape. The team uses this feature to calculate the amount of materials during planning and budgeting, which is viewed as value-adding among the participants.

A general interest in technology and 3D design software

When discussing what led the designers to learn 3D design software, the three designers share a common personal interest and curiosity in technology. Participant CS103 first discovered the software at the start of the COVID-19 pandemic and downloaded [Software Vendor B]. The participant watched YouTube tutorials to learn the software. Participant CS103 states,

> *I find technology in general quite fascinating. My husband is an industrial designer, and they have been working with 3D programs for the last 20 years. So, it's not new in that industry…I see it as very visual. I like beautiful things, and how I can make things beautiful in 3D. But I also like technology and different programs.*

Interestingly, both Participant CS103 and CS104 joined Company 1 at the same time in January 2021. Prior to joining the company, both participants worked for another leading apparel/garment manufacturing company in Denmark within different departments. Their previous employer was not utilising 3D design software, but Participant CS103’s department began to investigate virtual solutions before leaving the company. Participant CS103's previous colleagues did not share the same interest in 3D design software and received a lack of support. Participant CS103 explains,

> *The designers were not really so excited about it, but I was really excited. I thought it was amazing…They laughed at me when I started studying. I was told that nobody is doing this in Denmark, and ‘oh, are you still studying that 3D?’ I got really sketchy comments.*

After joining Company 1, Participant CS103 found support from the 3D team leader, and continues to feel highly supported by Company 1 in developing digital skills.

Participant CS105 had a different personal experience with 3D design software. Originally, working as the sample room manager in Company 1's production office in Türkiye, Participant CS105 states,

> *When Company 1 started to use 3D, suddenly the number of samples we had to do was falling very fast. I was thinking, have I missed something? I said I would like to look into this 3D. Then I started by studying from there by myself…*

Participant CS105 made the decision to move back to the head office after seeing great potential in 3D design software. Participant CS105 states, *“This is the future. This is what I would like to do, and I do see big potential instead of sewing the samples.”*

The design process

When asking the design team, *'How does 3D design software impact their creative process, such as hand sketching',* Participant CS105 and CS103 comment there is rarely any hand sketching within their role. A rough sketch might be used if they have an idea or need to explain something quickly to a pattern maker or customer. However, there are no 2D technical drawings or illustrations created. When presenting a style or suggesting a detail, such as a neckline, the team will create a digital collage during the planning and research stages. The 3D virtual prototype starts after the research and planning stage is complete. For Participant CS104, the starting point in the software is when the creativity happens.

Both the client and designers work closely to give and receive input on the design, style, or details. Not all tasks are carried out in 3D design software. For instance, trend research is carried out in a traditional way through exploring the latest trends from forecasting websites and following social media. For Company 1, this process is not automated, and the team manually creates digital trend boards to be presented to the client. Participant CS105 comments,

> *It's not like I get an idea, and I need to fulfil this. It's often agreeing with the client. Does this have interest? And then the creative process begins because it's maybe not as creative as some designer's job.*

Participant CS103, however, disagrees because the team is asked to provide a great deal of input in the styles developed. Nevertheless, the design team finds 3D design software inspiring in a variety of ways – such as the ability to test ideas prior to making a physical sample. Participant CS104 explains, *"You can just delete it. When I worked at another company, I had a flat drawing and a piece of fabric in my hand. Now I can actually combine those two and see them together straight away."* Participant CS103 feels that 3D design software forces the designer to consider their personal interest, and Participant CS105 adds that it makes a designer think about *'what is possible'*. Seeing the garment move in the software and how it fits through the fit maps inspires both Participants CS103 and CS104. Participant CS103 describes the visualisation of 3D virtual prototypes as 'very beautiful' and communicates the realism of a physical product.

When asking the designers *"Do you feel motivated to learn 3D design tools?",* the participants highly agreed. Participant CS104 believes that being a part of the 3D virtual world is essential, and states, *"...You always want to see what's coming next. What is the new thing?"* Participant CS103 also responds that designers must keep evolving and learning. New software need to be explored and experimented to see what can be added to the workflows. Participant CS105's personal motivation to improve processes, to create efficiency, and find ways to automate within existing workflows drives the participant to learn. Participant CS105 states, *"I'm always* *thinking how can we do it better? How can we do it easier? How can we make it less complicated, and that's also going for the 3D."* As the company continues to invest in its employees through ongoing training in digital technologies, the three designers feel highly supported by Company 1 in learning of new digital technologies.

7.6.2 Patternmaking/ Technical Design Team

Similar to the Design Team, both participants from the Patternmaking/Technical Team feel highly positive towards 3D design software. Personally, the participants describe the transition to the software as 'reasonable'. Participant CS107 had no objections when starting to use the program. If there were any doubts, the participant would ask questions. Like Participant CS103 in the Design Team, Participant CS107's partner also works with 3D design software in the construction industry. Participant CS107 states, *"Maybe this is why I thought, 'finally we are starting to do this'."*

Both participants have witnessed Company 1's adoption and implementation of 3D design software and the transition from hand draft patterns to 2D CAD applications. Participant CS106 has not used paper patterns for twenty years. Participant CS107 comments, *"Patternmakers don't need paper patterns nor need to cut patterns. It's even more old fashioned."* However, Participant CS106 suggests that students need to learn garment construction through physical training through paper patterns to construct garments virtually. Participant CS106 states, *"I understand by practising. Each style I learn something new from construction, new fabrics, and designs."* Interestingly, Participant CS106 reconsiders their response, and raises the possibility that new students may not need to learn from paper, as they are familiar with computers. However, both Participant CS107 and CS106 believe age is not a factor in learning 3D design software. Participant CS107 states, "*If it is interesting to you, you will do it."*

The participants feel 3D design software is more suitable for designers – *not* for pattern making and production. Participant CS106 feels the software is limited in garment construction capabilities but feels positive in the potential for future developments. Participant CS106 states, *"Maybe in the future it will be the one, but now when I try to work with grading or how to measure, there aren't enough* *functions at the moment. But 3D is very good."* As discussed above, the Design Team finds having access to make amendments to the digital file without the technical team is an advantage. Interestingly, Participant CS105 explains this is also a disadvantage, and states,

> *Sometimes you don't want to share the pattern…when I get the pattern, I might go in and say why did you do it that way? It's good we can learn from each other, but when too many people have an opinion about the same thing, sometimes it can get complicated.*

Once again, communication is highlighted as a main benefit of 3D design software. The Patternmaking/Technical Team has found that communication has become clearer therefore resulting in time savings. Participant CS107 states, *"Before, we were having to work with pictures, phone calls, or emails. It was difficult to communicate between client and patternmaking. 3D has made this easier."* Additionally, the participants find the capability to calculate costs by visualising the design and making adjustments virtually, such as cutting out excess fabric or reducing the length to meet the client's budget price, to be a major benefit. Before the software, some styles were difficult. The team would often make small scale patterns to test and configure the order of operations. Therefore, being able to virtually sample minor corrections without physically making a garment makes the process more efficient. The traditional way of working took three days up to a week to receive the physical samples at the Lithuania office from Türkiye or Bangladesh. By using 3D design software, the team no longer has to wait for physical samples to calculate the time. All tasks, such as patterns, prototypes, and sewing instructions can be prepared virtually. If a physical sample is needed, the sample will be made in the production facilities in Türkiye, Bangladesh, and Ukraine. As a result, the Patternmaking/Technical Team has not worked with physical samples in the last five years, and Participant CS106's role is now carried out remotely from home in Lithuania. The team uses email or phone to contact a technologist if any problems with sewing or workmanship arise.

When discussing challenges the participants have faced with 3D design software, Participant CS106 found few challenges because the training sessions with [Software Vendor A] were helpful. For Participant CS107's team, some designers were happy and motivated to learn, but others found the technology challenging. Participant CS107 explains,

> *With 3D design software, you need to always be learning, and keep learning and practising with these programs. If you don't, your 3D doesn't look nice. So, you always need to keep looking deeper and deeper in this program.*

Both participants find it challenging to keep up with new software updates alongside their day-to-day tasks – which includes making pattern corrections, ensuring patterns are correct for production, and managing their teams. In addition, the Patternmaking/Technical team is the link between the design team in the head office and the production teams. Participant CS107 states, *"If we have a lot of jobs, we need to work with speed. We have this pressure, and you try to be fast and while having the required quality."* As a result, planning is highly critical within their role, and the pressure to succeed and the expectations are difficult to manage. Participant CS105 states, *"I think we are expecting more from ourselves and each other. Like we need to keep getting better we need to keep improving and that's all dependent on ourselves."*

7.6.3 Resistance of the original design team

Participant CS101 faced a high level of resistance from the original design team when first introducing 3D design software. Participant CS101 shares, *"The first time I introduced 3D to the design team, I was told they didn't say a word when I left the design room."* Two weeks later, the designers approached the participant to explain that the software was not a good investment. Participant CS101 shared their response,

> *We [the designers] think it's because you are an accountant and looking into figures. You don't know anything about design, but our expertise is in design. We're using Adobe Illustrator working in 2D, and that's what our customers want us to do. So, let's please forget all about 3D, and we can continue to work in the way we've always been working. This isn't relevant for us, more or less.*

When asking Participant CS101 and the Design Team why they think there was resistance with the original designers, Participant CS101 comments that it is a natural human response to change. One of the original designers was more resistant as she was trained to draw by hand and spent 20 years working in this way. In Participant CS105's opinion, the original design team was 'forced' to change, and states, *"That's how many people react with something new. You're afraid because you don't really know it. Then it's easier to carry on the track you're already on instead of changing it."* In addition, Participant CS101 also suggests a generational gap in mindset and the use of IT technologies is another reason for resistance. Participant CS101 explains,

> *I think the average age of the designer we had before was about 45. Now the average is around 30. So, there's a difference of 15-20 years, and that makes such a big difference. You have the same problem at other manufacturers and at the brands of their understanding.*

The original designers no longer work at Company 1. The design team went from six designers down to two main designers. However, this is not a result of the technology replacing the designers. The unwillingness to accept the new way of working is what led to the original team to leave. Participant CS105 explains there needs to be a united belief amongst all stakeholders in the way Company 1 plans to move forward. Participant CS105 states, *"Trying to believe is not enough. We really want to go all the way with 3D. So, if we don't agree then we must go different ways."* Other companies have shared with Company 1, that they too, are finding the same challenge of resistance when introducing 3D design software to their design teams.

7.6.4 The evolution of the fashion designer

Participant CS101 considers the current designers at Company 1 to be more technical and production minded compared to previous designers. Meaning the designers understand that their designs must be optimised in the use of fabric and in cost. In addition, as discussed previously, all three designers share a strong interest in technology and willingness to learn new digital applications. Participant CS101 states,

> *To be a designer today and in the future, if you want to survive in the long run, you simply need to have an understanding of the technology and have an interest in what is happening afterwards. That's the only way that you can do responsible design.*

Often the initial designs from the brand/retailer will cost more than the set target price. It becomes the manufacturer's responsibility to make adjustments such as reducing the amount of fabric or alter original style lines to utilise as much of the fabric as possible. Participant CS101 explains, "*The designer at a brand doesn't care about that because that's not their problem."* Participant CS101 suggests brands need to consider optimisation to be more responsible, and it is in their best interest utilising as little fabric as possible. Participant CS101 states, *"Some brands don't care about how their production is running. They have a picture on a screen in a PDF file, and they say fix it. Make this…"*

All the participants believe designers should be practical instead of 'emotional', believing they are 'special', and 'living in a dream world'. In the opinion of one participant, emotions drive too much of the decision making. Participant CS101 also comments,

> *I think a lot of designers and creative people in general are living in a bubble…They think so highly about themselves. How clever they are…We have had some designers that have said, 'Now you ruined my design. If you reduce 2 centimetres, everything will crease. Then it doesn't have my touch.' This kind of attitude in the long run is not working. When working with brands that normal people can afford to buy, mass production, then we also have to get better.*

It is acknowledged that brands and manufacturers have different objectives and skill sets regarding design. As a garment manufacturer, two reasons for requests of Company 1's services are as follows:

1. The client requests production of a design.
2. The client wants input on current trends and design services.

The creative and technological knowledge are divided and siloed into the two categories; however, both are needed for product development. Interestingly, Participant CS105 would like to see more technical designers develop design thinking skills, and fashion designers with more technical knowledge. However, the participant feels there are few who can do both. Participant CS105 states, *"Patternmakers show what is reality. They don't worry about making things look nice."* The design participants believe that future designers will need to have some knowledge in patternmaking to work in 3D design software. Participant CS104 states, *"People working in [Company A Software] are both designers, technical designers, and photographers, as well as a stylist because you need to know a lot to get the right expression out of it."*

Eventually, Participant CS105 predicts 3D design technology will allow both the role of patternmaker and fashion designer to merge into one. Participant CS103 believes that working in 3D design software can teach designers patternmaking, and comments, *"You can actually experience it. Try, fail, try again."*

Participant CS104 discussed developing a stronger knowledge about garment construction working at a manufacturer compared to working at a brand. Participant CS104 states, *"At the other company we would just send drawings to the factories, and then we get some styles back. I had no idea what was going on out there."* Participant CS105 aims to train Company 1's patternmaking/ technical designers to think more creatively similar to fashion designers.

Despite the prediction of the roles of fashion and technical designers merging into one, some of the participants strongly disagreed that virtual technologies would lead to job loss for designers. However, the role will evolve over time requiring a different set up skills. Participant CS105 states, *"I'm not concerned. I would be more concerned for those who are not open to 3D. I think people just need to educate themselves and move to different kinds of tools."* Participant CS104 feels designers can be convinced by seeing the opportunity and benefits of digital tools. It is acknowledged however that utilising 3D design software has proven that less designers are needed to carry out the role at Company 1. Moreover, it has eliminated specific tasks– such as needing a stylist or part time photographer. Participant CS104 comments, "*It's tasks like that where we don't need them because the program can provide us with the pictures. We need to do the renderings from there."* Instead, the company has found a need for more patternmakers / technical designers.

7.7 Challenges and limitations of virtualisation and digital technology

When discussing the challenges of virtualisation, many of the participants specifically mentioned IT issues. For example, 3D design software needs the right hardware to function, which can be expensive, and file sizes are too large to share. As previously discussed, finding a suitable PLM solution is challenging, as the current system still requires manual steps.

7.7.1 The tactile element of garment creation

Another challenge mentioned by participants is the missing tactile element during product development. 3D design software displays areas of pressure or tension the garment might have on the body through fit maps, but Participant CS105 asks *“How do the pressure maps feel?”* Depending on the material, the red or green can mean different things. Participant CS105 believes the tactile element is necessary as a producer of physical garments because hand feel plays an important role in the emotional value of a garment. Moreover, a physical comparison is needed for the time being, as the industry begins to trust virtual garments. Participant CS105 states,

> *I think if we just emptied the whole company of all samples, I think some would ask 'what do you mean by that' or 'how is it really made?' We still need to have some sort of sample library where you can go out and see.*

Participant CS101 argues that the ‘lack of touch’ is not a relevant concern regarding the customer, as decision making in manufacturing is ‘not random’. Often designers know what materials they will be using. Participant CS101 states,

> *We both know the qualities of the fabric and how it functions while sewing. The designers, buyers, and our customers only have to focus on what they see on the screen. They don't need to think so much about how the fabric feels because they know already.*

Most of Company 1’s clients on average have around 5-8 different fabrics and limited in choices due to the need for specific qualities. The main focus is how the fabric looks, fits, and the details once the garment is constructed.

7.7.2 Clients learning to 'trust' virtualisation

When asking participants *'is virtualisation a worthwhile investment'*, all the participants agree. However, many participants discussed that clients need to be convinced. As discussed previously, the COVID-19 pandemic convinced clients to accept the virtual garments, but Participant CS108 argues, *“The demand is not* *driven because of a mind shift. It's more of a trend, but it's a completely different conversation and workflow."* After the COVID-19 pandemic, Participant CS105 saw the demand for physical samples rise as shipping returned to normal and suggests there is a disconnect in understanding the function of a 3D virtual model over a physical sample. The client will still ask for a physical sample after seeing the 3D virtual model. Similar to the sales team, Participant CS105 states,

> *We also try to challenge the client and educate them in 3D…If they take the time, they can see it all…What they're seeing on the screen and on the avatars is actually what they're going to get with the production sample 'in real life'.*

For example, when a client came to visit the head office and asked for the physical sample, the design team took the client through the traditional process of making a sample. Then the process was compared to the 3D virtual workflow. Participant CS105 shares,

> *They were like 'WOW! They are the same!'…To say one thing and just send it to them is not enough. We need to bring them through the whole process, and currently it needs to be done physically standing together saying here you have the dress and the screen with the same dress. Then it's easier to make an impact.*

This in turn led the client to 'trust' the process and has made the decision to work in this way. Participant CS105 acknowledges that physical samples are still needed because of their business model, but not as many as before. Participant CS105 comments, *"We have definitely reduced it. It was a very positive experience for both of us."* Many other participants mention their clients lack trust in the 3D virtual modelling process. Participant CS103 believes as virtual software develops, more clients will most likely accept virtualisation. The Patternmaking/Technical team found it took up to a year to convince clients that the 3D virtual prototype was the same as the physical. Participant CS107 explains that clients could not understand that minor corrections could be fixed in the software.

7.8 Case Study 1 findings and discussion

One of the main takeaways from the onsite visit at Company 1 is that garments cannot be solely based on art and aesthetics. Instead, they must be carefully engineered for functionality. While avant-garde and digital-only fashion may have their place, the reality of physical production is that garments are made in and for a physical world involving finite raw materials. Case Study 1 illustrates the complexities of the traditional product development process throughout a garment's life cycle.

Virtualisation and technology raises questions about the current role of the designer and the skills – or lack thereof. While designers are highly regarded for their creative vision that drives the industry, the vision cannot materialise without the technical expertise of patternmakers/technical designers who transform these visions into physical products.

Moreover, the case study provides practical evidence of the significant impact 3D design technology can have on an organisation. Company 1 has found that this technology has greatly transformed their workflows, demonstrating its value through cost savings, productivity gains, and return on investment. Technology is viewed as a tool to support business development and growth through:

- Reducing waste in the prototyping stage, complimenting larger environmental and social responsibility initiatives.
- Supports in ensuring an organisation's accountability for ethics, transparency, and responsibility (e.g. certifications, investment in innovation, sustainable dyeing processes, reporting data, etc.).
- Foster unity in mindset and open communication across product development teams, enhancing efficiency and effectiveness.

The implementation of 3D design technology marks the beginning of Company 1's virtual initiatives and adoption of virtual solutions. Despite the current challenges of virtualisation such as IT challenges, lack of software development, and change in mindset, Company 1 is eager to explore further opportunities and expand into production.

While some might argue that Company 1 is not a representation of the majority of manufacturing organisations within the industry, it demonstrates that ethical practices can coexist with profitability, enabled by virtual technologies. As the week progressed during my visit, the conversations shifted from technology to an emphasis on people, processes, and systems. One can see the comradery and a strong conviction of the stakeholders in doing what is ethical even if it means turning away clients. There is mutual respect and equality, which governs the organisational culture and guides business decisions. Participants at Company 1 acknowledge that their approach may not be suitable for the entire industry. Nevertheless, there are many lessons to be learned and principles to be applied from Company 1 to create a better and more responsible fashion system.

Chapter 8: Case Study 2 Report

8.0 Introduction Chapter 8: Case Study 2

This chapter presents a discussion of the findings of Case Study 2. The purpose of this case study is to gain insight into how virtualisation of the product development process is being undertaken in the fashion and apparel/garment industry through observing the inner workings of Company 2. The organisation makes for an interesting subject as it was founded to disrupt the fashion system through the exploration of digital technologies to support new business practices. This case study explores emerging themes of digital fashion, micro factories, and open-source fashion found in academic and mainstream literature to support findings for the PhD research objectives. This chapter is outlined as follows:

- About Company 2 – The original studio
- Defining a 'digi-physical microfactory'
- Digital transformation
- Company 2's 'digital' toolbox
- The impact of 3D design software
- Limitations of 3D design software and digital assets
- Open-source philosophy: a conceptual vision of an open source microfactory
- Company 2’s roadmap to open-source platform
- Exploring Industry 4.0 technologies in relation to open-source fashion

The next section introduces Company 2, providing context for this chapter's discussion.

8.1 About Company 2 – The original studio

Company 2 is located in Gothenburg, Sweden in the Manufakturgatan district – a creative community of a variety of small businesses ranging from cafes, film production, bakeries, and fine art studios. This inspiring location is ideal for an organisation like Company 2, which was formed out of curiosity and exploration.

Before developing Company 2, Participant CS201, with a background in men's tailoring, undertook a PhD exploring theoretical models of garments construction to influence new methods. Participant CS201 states, *"…the theoretical background underpins the design construction called kinetic garment construction, which is the basis for the majority of the design commissions we do…"*

From the participant's PhD study, there are two main ways garments are constructed. The first is drafting 2D flat patterns of a garment based on horizontal, vertical, and key point measurements. The second is draping fabric onto a dress stand. Participant CS201 explains, *"It's 19th century thinking. It was all defined in the 1850s, and even though it's been refined, the general theory is still untouched."* These methodologies have become a standard way of teaching and understanding garment construction to date. Participant CS201 states, *"In my experience, design schools and a lot of designers try to do something different or break with these norms, but quite rarely have I seen anyone suggesting another alternative model."*

Participant CS201's kinetic method was based on French designer Genevieve Sevin-Doering – who also experimented in draping garments in one piece onto the intended wearer. Sevin-Doering was trained in Paris and developed her method by studying prehistoric tailoring of historic garments in relation to movement of the body. However, Participant CS201 explains,

> *She never really formulated another theory explaining her work. I think very few artists do generally explain themselves… It's more the common thing for artists or designers to argue their work is their language. So, what I did was very much trying to formulate a visual theoretical model.*

After working in Sevin-Doering's studio, Participant CS201 also noticed the apprentices struggling to articulate their way of working and reasoning when it came to complicated styles. It was clear to Participant CS201 their method deviated from traditional tailoring. Observing Sevin-Doering, Participant CS201 found a similarity to the theory of *'Langer Lines'* – the direction in which the skin wraps around the body, often studied by surgeons. Participant CS201 states, *"I found a large level of congruence between the bias stretch or the fabrics when draping in the manner she had done."* Where the body expands when moving is an identification of where a garment should expand or needs added ease. This insight led Participant CS201 to incorporate Langer Lines into their own practice, shaping the innovative approach evident in Company 2's business model and ethos. Participant CS201 states,

> *It's not only to put a theoretical model for making funny patterns or garments, but also to hopefully inform designers or viewers to see garments differently. I think in design education, apart from making and skills of stitching or drawing, designing is very much learning to see differently always.*

After completing the PhD, Participant CS201 was keen to apply the findings to a new project. However, where to start and what the project would look like was unclear. In 2015, Participant CS201 with a former business partner, began exploring virtual solutions, which led to discovering 3D design software [Software Vendor B]. The following year, the project turned into a fashion studio or a 'laboratory'. The studio aimed to rethink the way garments are designed, produced, and sold by utilising virtual solutions (Company 2 Website, 2022). Participant CS201 states,

> *We quickly decided to treat that project as that. If we start a brand on a small scale without any big investors, we could see if we can digitise the whole process. Which is still a big problem for all big companies because of course you can't change an organisation overnight if you have a business running… Because you might not have a business.*

Experimenting with 3D design software led to developing the concept of 'Sharewear' – an online platform where 3D digital garments can be downloaded, and production ready patterns can be printed at no cost. Interestingly, the two partners found a high interest from hobbyists and home sewers. One client in particular purchased a physical shirt from the Sharewear platform, downloaded the pattern, and redesigned the garment. The client contacted the studio requesting to send the modified 3D digital file along with personal fabrics to be produced at the studio. Participant CS201 states, *"He used our microfactory as what he called his 3D printing service for his design, and I thought that was brilliant!"* The team made the client a couple of shirts and made further developments of the design for a product drop. This inspired a new discussion for Participant CS201: *"What will a brand be when information and software work with the design information?"*

In 2020, the original studio split in half as the two partners began to explore personal areas of interest. The original studio became a brand and communication consultancy, and Company 2 became a microfactory focusing on apparel/garment production. A series of events led to what Company 2 is today. For Participant CS201, it was the vision of the original studio of experimentation, the business model of pre-order garments, and the use of digital technologies that enabled conversations around new processes within product development. Furthermore, carrying out production, sourcing, and communication abroad led to many challenges for the original studio. As a result, Participant CS201 was eager to bring production to Sweden, but this would raise two main challenges: 1) Sweden being a high-cost country to produce in 2) a lack of labour force with proficient technical garment skills. Participant CS202 states, *“We have much higher salaries than everybody else. I would say we are one of the most expensive factories in the world because of the salaries. There are very few compared to other parts of the world.”*

In fact, Sweden has a history of garment and textile production in Gothenburg and the outer region in Boras, which is a well-known textile district. In the early 1900s, Participant CS205 explains Sweden produced garments and textiles before being outsourced to Asia. Once more, an interest in garment and textile production is emerging. Participant CS205 states, *“Over these last few years there are a lot of microfactories and micro production sites appearing on the market.”* These microfactories in Sweden aim to create a community, and Company 2 is eager to assist. Participant CS205 states,

> *Instead of working against them, we're trying to create a Swedish textile industry again. Especially since we are in this part of Sweden, we have the Swedish school of textiles and the Swedish Trade and Employers Association (TEKO). There are deep roots here in this part of Sweden and we're trying to build it up again.*

Around the time Participant CS201 started Company 2, the Syrian Refugees crisis led migrants, mainly from Aleppo, to Gothenburg. With Aleppo previously known as the textile centre of the region, Participant CS201 explains, *“Suddenly there were a lot of unemployed tailors coming here with industrial experiences.”*

8.2 Defining a 'digi-physical microfactory'

Defining Company 2’s business model is challenging as the digital and the physical are intertwined. Both are equally important by working simultaneously to support traditional manufacturing methods and digital experimentation. The company defines itself as a ‘digi-physical microfactory’. To gain a holistic understanding, it is helpful to break down and define each:

A ‘digi-physical’

Starting with defining ‘digi’ and ‘physical’, the term is describing two different identities:

1. **A ‘Digi’ Factory**: The experimental side of Company 2 exploring digital technologies, seeking unique collaborations, and pioneering projects to encourage thinking outside the traditional design, make, sell business model.
2. **A ‘Physical’ Factory** (a traditional manufacturer): Company 2 remains a fully functioning factory offering services involved in the production of physical garments for the physical world.

A ‘Digi’ Factory

What makes Company 2 an intriguing subject is the variation in portfolio of projects the company undertakes. Part of Company 2's identity is to explore new digital fashion frontiers such as non-fungible token (NFTs) collections and decentralised fashion systems for the development of practical frameworks. Each client is offered a bespoke service. Participant CS202 states,

> *We have so many legs to stand on, and that's also what makes it fun for us. Because neither me or [Participant CS201] wants to be stuck in one company doing one thing. We want to be able to do a bit of everything.*

Participant CS204 feels there is added value in working at Company 2 by not having to commit to creating collections and *“producing to just to produce”.* Participant CS204 states, *“I think it’s really quite nice not just making clothes, and hope that people would buy it based on your branding. Instead, make clothes that often already have a special meaning or context."* Nevertheless, unique collaborations are not only related to virtual technologies. Company 2 produces speciality technical garments – such as protective wear, motion capture suits, military uniforms, etc. These clients are more interested in Participant's CS201's kinetic design research and method to product development.

A 'Physical' Factory – a traditional manufacturer

Company 2 is progressive in the way it utilises technology, but the Company still operates as a traditional manufacturer. Participant CS201 states, *"We do both things [digital and physical]. Right now, quite a big part of what you do in the factory is only physical things such as the heat and TSD products. It has nothing to do with visualisation."* Participant CS202 further explains many companies are working with 3D design software within their product development, but often do not own their factory. Participant CS202 states, *"We have an A-Team of micro factories around us, but they are more or less, maybe more like an atelier or a studio than a factory."* The participants feel that having both a factory and 3D design capabilities are a competitive advantage.

Clients request specific services including production only or design development for patterns to be sent to their suppliers. These clients are mainly interested in physical production. However, full production orders allow Company 2 to operate in a high-cost country and to be experimental in digital focused projects. Participant CS202 states, *"We still want to have a real factory, and the real factory needs to have work. It cannot all be these 10 pieces, 20 pieces. It needs to have proper production."*

In addition, Participant CS202 must carefully consider 'the right client' to ensure it is financially viable for both parties and the Company is producing a variety of product mixes. For example, if Company 2 has a client in cycling and running wear, the company will not onboard a similar brand or product category unless it is only for production. As a small business, resources are limited. Participant CS202 states,

> *We try to think: what do we want to do, and what will they be able to afford to have made in our place? So, I'm active in connecting with different clients just to get the spread because we can't do T-shirts. We're going to be too expensive. We can do a project with 300–500 t-shirts, but that's it.*

Clients are turned away if the job is not economically viable for both parties. However, Company 2 will refer them to other factories better suited to their needs, and the other microfactories do the same. Participant CS205 explains, *“It’s about being inclusive in how we are trying to be progressive and to create the same place as the textile and fashion industry was back in the day.”*

Regardless of if the project is for the virtual or physical world, digital technologies are utilised in the product development process. For example, when the factory receives a production only order, the team will continue to digitise and test the production pattern in 3D design software.

A ‘microfactory’

Defining a ‘microfactory’, Participant CS205 explains, *“Everything, apart from creating the fabric itself, from the start with design can be done here. We are really changing the value chain by having everything in house like this.”* The microfactory is made up of the design team, product development team, and production team. Participant CS203 states,

> *To work in an environment where you work with the client, designer, and production in one place is really a great place to learn. Because if you work for a bigger company there is a huge disconnect between design and the production. Here you can directly talk to everyone involved in this process.*

Interestingly, what differentiates Company 2’s from other microfactories is the ‘digi-' element – or the use of digital technologies to support the product development process for production. Participant CS201 explains,

> *What we do here I think is quite unique. We have a very high level of digital development possibilities combined with a high level of physical sample possibilities. Together with the design knowledge, we can do very complex developments very quickly.*

Company 2 participants believe success requires a community of local developers and the feasibility to create products to sustain a microfactory in a high-cost country. Participant CS202 states, "*So it's not like we are saying we need to do everything here. We think that the production should be close to where the people are.”*

8.2.1 Technology selection process

Selecting technology must be carefully considered based on what the company wants from the technology and if the technology supports developing digital production. Participant CS202 states, *"...But that costs a lot of money, and we need to do it slowly together with the clients…As they want to add their own products, it is easier for us to buy new machines and update the lines."*

Throughout discussions with participants, having a similar mindset and the emphasis of community and partnerships are consistently mentioned in the growth of the organisation. This also extends to Company 2's clients who share the identity as '*co-creators'* – defined as those "*who create with us."* Participant CS202 states, *"We want to build relationships with clients, so we can grow with them. To be able to grow with a client, we need to have the right type of clients that can start in the factory as it is…"*

The next large investment the team is exploring is a CNC which can cut single layers or several layers of fabric at once. In addition, the company is exploring a robotic arm.

8.2.2 Onboarding talent and finding collaboration

In response to the digital skills gap in the industry, Participant CS202 notes that many tech-savvy individuals approach Company 2. The diverse range of projects the company undertakes creates networking opportunities. The nature of the business draws both employees and clients for its 'progressiveness' and agile product development. Participant CS204 states,

> *I applied for the specific place because of the way [Company 2] works with technology and digital tools…Also how the company tries to drag a very old fashion industry into a new direction and try to kind of rewrite how we have done things before which I think is quite cool…*

Interestingly, the main challenge is finding individuals with the technical skills and training required for a variety of garment techniques to carry out physical production. Participant CS202 explains, *"A normal factory, where many people are used to doing* *one type of seam for 20 years, right? Here you need to be able to do everything. That's harder."*

8.3 Digital transformation

Company 2's digital transformation journey differs from the majority of the industry. Participant CS201 explains, *"We're not transforming from something because we've been digital from the start."* Participant CS205 adds that digital transformation is crucial for pioneering positive impact in Sweden and the industry. Participant CS202 states, *"I would say Participant CS201 is one of the first to bring the program into Scandinavia or maybe even Europe. So, we have a lot of knowledge of the program."* Digital transformation will remain an ongoing journey for Company 2 as they explore technologies to further connect the value chain. Participant CS205 states, *"I hear the vision Participant CS201 talks about with digital transformation. I think what it will become will be something incredible like custom made garments. It could be more adaptable. It will be more connected."*

8.3.1 Benefits of digital transformation

All the participants strongly agree that digital transformation is a worthwhile investment, citing several reasons. Participant CS204 notes that most industries are advancing towards digitisation and automation in their operations. Moreover, the participants emphasise the importance of digital transformation for organisations to stay relevant. Participant CS204 explains,

> *In general, I feel like there's a tendency for more digital fashion. NFT's are becoming more of a thing. So, it's also moving with the customer and trends that are evolving in the world. Therefore, it makes sense to digitise as much as possible and move with the times.*

The discussion of digital transformation naturally led to the benefits of 3D design software. Participant CS204 believes that organisations should move with technology to sustain their business by saving time and reducing the number of initial samples. The participants agree digital tools accelerate daily tasks – such as digitising the manual process of editing patterns. The advantages of 3D design software will be explored further in Section 8.5, *The impact of 3D design software*.

8.3.2 Challenges of digital transformation

The participants mention a number of challenges regarding digital transformation such as:

- IT related issues – files are not capable of withholding the size of some designs. Specifically, PLM systems have been mentioned in relation to accessibility and connectivity between Company 2 and its clients.
- Training staff presents challenges, as not everyone is eager to learn or adapt to new technologies.
- Determining who will be affected by digital technologies, deciding where along the value chain to implement these technologies, and selecting the appropriate technologies are key issues to address.

A main challenge highlighted by participants is the need for education and awareness around digital technologies, such as 3D design software, and new ways of working. Participant CS203 states, "*There's still really a lot of customers that do not know the potential of 3D. So, we are one of the ones pushing for it as well.*" Convincing large companies to undergo different transformation is particularly difficult due to the numerous different stakeholders and departments. For these companies, determining where to start and how to implement new processes can be challenging. Participant CS202 observes that change is slow, but states, *"Many have started. Maybe only with the design, but now we are talking with the pattern designers to show them that we don't use our other systems anymore."*

Despite the interest in Company 2, Participant CS202 believes clients are hesitant to fully embrace Company 2's digital workflow due to fear. For example, at Company 2, there is no distinction between a pattern maker and a designer. Both roles are carried out in 3D design software. Participant CS202 acknowledges that this approach is more feasible in a small company. Many of Company 2's clients have their own design system where the roles of designer and patternmaker are separate roles or outsourced abroad. Participant CS202 explains,

> *You have the designer making the drawing...and then you just send it off. Then you will see a sample in the end. There's going to be a lot of steps in between before the designer sees the actual*

> *garment…You need to have a connection…for us it's a collaboration. So, you should do it together.*

Additionally, Participant CS202 highlights the need to explain the process to CEOs and upper management, given the high upfront costs. These factors should be considered during planning and budget meetings. Companies may find it as a worthwhile investment once patterns are digitised and the foundational systems are established. Participant CS202 states,

> *A lot of brands are just tweaking designs or maybe changing colours. You'll be able to do it in the computer in the design stage where you can always have the fabric included in the design and the visualisations.*

Participant CS202 also explains that the upfront cost and the initial time required to set up a digital workflow are often barriers to adoption. However, the participant strongly believes that the long-term savings will make the investment worthwhile.

8.4 Company 2's 'digital' toolbox

Company 2's workflow involves a variety of virtual assets and technologies such as the following:

- 3D design software
- Rendering software – Blender
- Animation software – Mixamo Adobe.
- Fabric digitiser and analyser
- Online open-source platform
- Virtual avatars

It is important to highlight that Participant CS01's creative process begins with draping the fabric onto a physical mannequin and sculpting the design. The shape is removed from the mannequin, placed on a clear grid, and scanned using a mobile phone. The image is imported into 3D design software to create a production-ready sample. Company 2 uses is [Software Vendor B] as the main software and starting point. All pattern amendments, design development, reviews, and fittings are carried out within the software. Participant CS201 states, *"When you import the file into 3D, you can simplify things in the software because you can delete pocket bags or other* *things."* This is when the product development shifts to a virtual process, while the creative process remains physical.

The 3D virtual prototype also informs the setup of patterns for production and the product information for clients. There are no 2D flat or hand drawings of garments. Company 2 has a 2D CAD software but is only occasionally used for some grading operations and layout for a specific client. Participant CS201 explains,

> *We generally assume we save time by not exporting and importing [files]. So, we spend a bit more time doing some operations like grading things, which is still slightly more complicated but doable in [Software Vendor B] nowadays.*

Participant CS201 emphasised that production and manufacturing remains traditional. Prototype patterns are printed using an HP printer, while production patterns are printed on a Gerber printer, which accommodates the full width of the fabric roll. Interestingly, the participant notes that setting up the production printer is complex and involves several steps. All 3D digital files created with the garment patterns must be production ready – including seam allowances, notches, and marks. Participant CS201 states,

> *We work with everything and every piece of fusing and every fold. I mean it demands a lot from us because we need to do both the visualisations and the production patterns simultaneously. It's not the normal thing to do, but at least from where I see things that is the way to go forward.*

Regardless of whether the garment is intended for production or the virtual world, all designs start in the 3D design software. To summarise, Company 2's product development process includes:

1.) Drape pattern pieces on a dress form or mannequin.
2.) Digitise patterns by scanning them with a mobile.
3.) Create a 3D digital visualisation of the garment before the first sample.
4.) Present the design to the client, adjust, and confirm style.
5.) Make the first prototype/ sample.
6.) Approve final design and prepare for production.

8.4.1 Product Lifecycle Management (PLM) Software

Company 2 does not currently use a PLM software as it is not essential for their organisation. However, once [Software Vendor B] develops its PLM software, Company 2 will explore this option. As discussed previously, Company 2 has faced issues with connectivity and access to their clients' PLM systems.

8.4.2 Digital asset libraries– digital garment and digital fabric libraries

According to industry literature as well as the interview participants, a developed digital asset library of basic pattern blocks, fabrics, trims, etc., is highlighted as a crucial component for an effective virtual garment workflow. However, Participant CS203 notes that for Company 2, developing a digital pattern library is not as critical. Participant CS203 explains, "*I think we have a lot of things that we make from scratch because a lot of clients want kinetic garment construction…"* However, a pattern from previous designs might serve as a starting point. The participant suggests commercial brands with established garment fits would greatly benefit from digital pattern libraries. Participant CS203 states,

> *I think the big companies have huge libraries, so I think they have better use of 3D libraries. They have a lot of new designs based on their previous, so they know the feel and fit of the garment. So maybe for them having a huge library of all the past projects is really good.*

The 'digital fabric library' however is an important priority for Company 2 – especially regarding their open-source platform. Company 2 keeps a basic library of colourless fabric for texture maps of print or colour to be applied interchangeably when needed – allowing the user to experiment. Participant CS204 highlights that prints are already digitised, and states, *"With the prints, you'll just get it as a file to be added on top. I think print designers mainly work in Photoshop."* Similar to the digital garment library, Participant CS203 states, "*I would love to sit with building fabric or trim library, but there are so many things for free that you can take so you don't have to."* There is an extensive amount of texture and fabric files available open source.

Each client has their own folder containing digital fabrics and trims. If a specific fabric is not in Company 2's library, a similar one is used. However, for some clients the importance of the physics properties to be accurate or a digital twin is crucial within their offered services. In addition, Participant CS203, highlights that not all clients want digital fabrics.

8.4.3 Company 2's Fabric Digitalisation Process:

An interesting component of this case study is Company 2's fabric digitalisation process. [Software Vendor B] offers its own digitising service; however, Company 2 prefers to carry out the process in-house. Participant CS201 states, "*What Participant CS204 is doing right now is making digi–physical fabrics or digital fabrics based on actual existing physical ones that are orderable."* To create a digital twin of the fabric, Company 2 uses the original fabric analyser provided by their 3D design software vendor. Digital fabrics are a large part of their open-source platform, as well as offering digitising fabrics as a service. Tools needed for digitising fabrics are as follows:

- The fabric samples
- The fabric analyser
- Rendering software
- Chosen 3D design software

Steps to digitise the fabric:

Participant CS204 finds utilising the analyser to be straightforward and requires little training – which consists of a brief online video. Participant CS204 states, *"It's very simple measurements of the behaviour of the fabric and its properties…It's more a process of being precise than a process of if it's difficult to do."* However, Participant CS204 explains the process is time consuming, as there are several required measurements. Depending on the properties of the fabric, it can take thirty minutes up to one hour in making the texture maps. Waiting for the fabric analyser to stabilise takes the most time. In addition, the time it takes to cut the fabric samples also needs to be factored in. Overall, the process is easy enough to carry out in-house. Company 2's workflow to digitise fabric is as follows:

1) Measuring the fabric by taking two samples of the desired fabric (x1) cut on the grain line and (x1) and the fabric analyser to measure as follows:

- Thickness of the fabric, which will require a waiting period for the analyser to capture.
- The 'bend' of the fabric by rolling the fabric through the device and waiting for the fabric to 'fall' is needed.
- The length of the fabric.
- The stretchability.

2) Input measurements and properties into the vendor's digital fabric software to create the digital twin model.
3) Scan the fabric using an office scanner and upload to Adobe Substance sampler to create the texture and image / print of the fabric.
4) Input and place the image on the digital fabric created in Step 2.
5) The file is ready to be used and imported in the 3D design software and other platforms.

When experimenting with 3D design software, Participant CS204 has found that the digital fabric does not match the physical fabric. The participant found this experience to be frustrating. Participant CS204 states, "*So there's kind of a gap between the digital and the physical.*" However, by carrying out the fabric digitalisation process, Participant CS204 has found experience rewarding by gaining an understanding of how the physical measurements translate into the 3D design software. Participant CS204 explains, *"It's a very nice experience to see this translation between the physical and the digital, and it helps me trust that it's accurate."*

8.5 The impact of 3D Design software

3D design software has significantly shaped Company 2. Participant CS203 states, *"It's everything for us. I don't think we can work without [Software Vendor B] because that's how we built the structure of the business."* The software supports Company 2's vision of pioneering industry transformation and innovation. Participant CS201 states,

> *So that has been my personal main interest in these things… When you create the possibilities, it opens up different business models, as*

> *we tested with the previous studio, and totally new distribution overall.*

The participants highlighted many benefits of utilising 3D design software, including improved communication, understanding of garment construction, and precision. Improved communication was noted for facilitating interaction between different stakeholders, such as:

- Design and production to communicate true design intent through 3D visuals compared to 2D flat sketches.
- Suppliers and interdepartmental teams benefit because the digital file contains a high level of information needed for manufacturing.
- Communication with international partners is improved, especially when there is a language barrier.
- Clients and Company 2 can discuss style changes in real time, aiding purchase decisions and visualising the intended garment before creating a physical prototype.

Participant CS203's believes that having a 3D visual is better for communicating with patternmaking and production teams compared to written instructions in traditional tech packs. Participant CS203 states, *"People don't want to read. Even if you write a really good tech pack, which includes a 2D illustration, people don't read them…having that possibility where people just see it and just understand it is really strong and helpful."*

Based on previous experience, the participants feel highly positive towards 3D design software. Participant CS203 shares that having 3D design software skills led to their current career and position at Company 2, and shares, *"I think it's amazing. I want to be a 3D designer in the fashion industry. It's been really good, really interesting, and it's never boring."* In addition, Participant CS204 has found that their understanding of garment construction has improved by working in the software. As a result, fewer mistakes are made when developing the pattern. Participant CS204 explains, *"You can use the software to disassemble it in the 3D program and see how it is constructed and where the different pieces go. I think that's quite valuable."* Visualising the design in 3D on the same screen where the pattern is created is helpful and offers greater precision. Participant CS204 states, *"I think to be more* *precise because you can't be more precise compared to a flat pattern on the table."* Instant decisions on the placement of design details, such as a logo, can be made.

Participant CS204 acknowledges that 3D design software is not for everyone, and many designers might see the technology as 'too technical'. Participant CS204 states, *"It's a bit more like tailoring. So, it really depends on how you want to work and also what kind of designer you want to be."* Participant CS205 also feels virtual technologies might be a challenge for designers who are used to crafting products by hand or sketching with pen and paper. Therefore, it may be difficult to translate their skill from an analogue process to a virtual one.

8.6 Limitations of 3D design software and digital assets

The participants also mention limitations of 3D design software and digital assets. Participant CS203 explains digital prototypes are not always correct. For example, top stitching can be incorrect, and the software does not allow the user to view seam allowance in the 3D view. Participant CS204 also feels the process of creating avatars needs to be developed to be more user friendly. The participant finds altering the measurements of avatars difficult to achieve the desired size and proportions. Participant CS204 explains, *"For example if you change the height, the length of the body, or it can get really awkward placement of the waist."* This distracts from the ability to visualise how the garment would look on a physical person because the avatar appears 'wonky' or disproportional. This prompted the discussion around virtual fit. In Participant CS204's opinion, a physical fitting of garment is more accurate than virtually fitting garments. Participant CS203 also agrees and discusses that fitting garments on avatars is challenging especially with certain types of garments – such as swimwear or garments which fit close to the body. The participants feel that avatars need to be more 'human-like'. Participant CS203 explains, *"The avatars are solid objects where humans are really squishy, right? So, the clothes feel different. Like they can't sink into the skin in real life."*

8.7 Open-source philosophy: a conceptual vision of an open source microfactory

A compelling theme to emerge from Case Study 2, is the concept of an open-source fashion system, in which Company 2 is exploring. The ethos on which the company is founded and operates shares commonalities with open-source philosophy. According to Mustonen (2013, p.11), open-source philosophy is,

> *Connected to the thought rule of the people (democracy) or the concept of 'open society', developed in the first half of the 20th century and is considered as a transparent, non-authoritarian system, where the citizens have the possibility to direct and flexible participation.*

Participant CS201 has considered the impact of digital technologies in other industries, which has disrupted the way products are designed, produced, and consumed. Participant CS201 states, *"I compare the music industry to the fashion industry because they both play with people's emotions somehow. There is a creative, a business, and a distribution part of it."* Participant CS201 predicts the same disruption of digital technologies will impact for the fashion industry, and states,

> *I think what we are facing now, with [Software Vendor B]'s open-source platform and other sharing selling sites, is that the tools for fashion production and development used to be in the hands of fashion brands. Now they are becoming available to everyone just like photography, or tools for music, or media making.*

With the ability to carry out design development through an open-source online platform, Participant CS201 questions, *"Are we then approaching the death of fashion brands? Do we need them?"* The emergence of brands began in the 1850s in Paris with the House of Worth. It was the first instance where consumers were sold what brands offered rather than having clothes custom-made by a tailor. This development also introduced labels with the brand's name. This coincided with the First Industrial Revolution and the diffusion of standardised production methods. Participant CS201 explains,

> *Together with industrialisation, ideas began to spread around the world. With garment manufacturing, these ideas connected how the sewing machine works. For example, it's easier to stitch along the grainline, and it's more difficult to stitch on a bias. So, it's natural especially with these sewing machines 200 years ago that wanted to stitch like that.*

The development of technology in the 1800s established the role of brands and enabled standard mass manufacturing processes. Participant CS201 states, *"I think it's interesting because branding sort of is as we know starts at the time of this shift in technical parody. Now we're facing what we're in the middle of another shift."* With instant access to online information, the participant draws a parallel to the changes brought about by the First Industrial Revolution in garment making and sales. Indeed, the rise of online communities may lead to new ways of working through open-source platforms.

Non-fungible tokens– NFTs and the Metaverse

Participant CS201 is seeing the digital and physical worlds begin to merge through open-source methods, and states, *"…So I think it's also some different things we are dealing with now that are digi-physical. Physical objects which exist both digitally and physically parallel to each other."* Participant CS201 envisions a practical application for Company 2 through a pre-ordering system that involves the consumer in the creation process. Additionally, major brands have shown interest in creating digital assets for the physical world. For example, Participant CS201 and a previous business partner were approached to redesign a kinetic tracksuit for esports as part of the first digi-physical projects with a major sportswear brand. Despite these brands making millions of dollars from selling sports teams merchandise, Participant CS201 explains,

> *Today kids don't watch football. They look at esports. So now they started sponsoring more teams to have the kids buying e-sport merch. They asked me if I could redesign a tracksuit for esports. So, we made it very comfortable for sitting in. Stupid, but funny.*

The first sample series became part of the brand's E-sport collection, and is now part of the brands motor sport collection.

For an organisation like Company 2, which has a strong focus on both the digital and physical worlds, one might expect the company to be interested in the virtual worlds such as the Metaverse. When asked about their views on the Metaverse and whether it is an area Company 2 is exploring, participants noted several potential advantages. They can envision new business opportunities and see the Metaverse as a platform for offering unique, exclusive pieces. Participant CS203 states, *"If we* *can buy clothes in Metaverse and you can actually have it physically, that's something really cool."* Other participants echoed this sentiment, suggesting that exploring the Metaverse could position Company 2 to meet further demands from clients interested in both virtual and physical experiences.

The participants also expressed doubt and hesitation regarding the Metaverse. Participant CS204 argues that it may not be a good investment, as there is a lack of general understanding of the concept. Participant CS204 explains, *"There are many who aren't attracted to this way of thinking and designing yet."* While participants are not opposed to the idea, Participant CS203 states, *"I just don't quite see where it's going."* Developing 3D virtual realities requires a significant amount of time and effort. However, Participant CS204 sees the value in spending time to develop 3D digital assets. Participant CS204 explains,

> *I think 3D objects will definitely be a part of the future. It's already too late to take it away…I think it will always be to your advantage no matter what the future scenario turns out with the Metaverse or NFTs. Those are something which haven't been discovered yet, but they will be a part of it.*

Participant CS203 sees the potential in the Metaverse for entertainment or as a virtual social hangout. However, Participant CS204 highlights that this scenario lacks human connection, and states, *"That's the same as what I would do in real life with my friends…I see it as a sign of humans being even more lazy if we have to just sit at home."* Participant CS204 would prefer an interactive system that merges the virtual with the physical world – such as AR. Both participants agree that a device capable of integrating the two beyond what is available and accessible at scale would be required. However, they remain hopeful for future technological advancements.

Company 2 is currently exploring an NFT project to test the concept of creating digital assets for the physical world. Participant CS205 explains, *"We are trying to get our heads around what is an NFT, and how we can create a garment that is an NFT. How can we package it for a potential client or our consumer?"* This project, in collaboration with *"a decentralised culture factory",* will initially involve a reverse-engineered Swiss army jacket from the 1970s. The jacket will first be sold as an

NFT, allowing the buyer to wear it digitally across various platforms. The NFT will be available to buy for a limited time, and the buyer has the option to trade in the physical garment produced by Company 2. Participant CS204 states, *“The point is being able to exchange your digital values for something you can actually use and feel.”* Questions may arise about who the target consumer is for this project. Participant CS201 states,

> *... I think the one interesting thing about this NFT community, or the crypto kids is that they are quite wealthy, a lot of them. They managed to sell this outfit for $2500 for a [jacket] and pair of pants in the process…Suddenly there is a totally different market segment.*

Participant CS201 compares this model to the classic fashion system where luxury brands target high-end customers. However, in this instance, aesthetics and luxury might look differently. Participant CS201 states,

> *The funny thing is that in this market segment, they like things looking digital. I mean the fashion industry's problem with these digital garments is how can we make it look like our classic glossy mag photos? While these guys like things looking pixelated. Hence the pixelated print.*

Participant CS205 feels the open-source platform will be the entry into the Metaverse to begin conceptualising the next steps as NFTs and the Metaverse develops.

8.8 Company 2’s roadmap to open-source platform

Despite the uncertainties surrounding digital technologies and the potential to shift paradigms, Company 2 is focused on translating theories into practical solutions. The participants believe this approach will create value within the product development process and ensure long-term success for the microfactory. For example, Participant CS201 explains,

> *If we have clients asking for a previous T-shirt, sweatshirt, or jeans then we could say instead of them having to pay us for several days of development, we could say that we have these five jeans as open source. You can choose from them and open them up in [Software Vendor B]’s open-source platform if you like. You can work with them yourself there, or they pay us for doing it.*

Company 2 is currently developing their open-source system. Participant CS204 states, *"It doesn't have a complete end goal yet. It's still being developed day-to-day and from these sites (e.g. software platforms, social media). It's a model."* In addition, open-source acts as a promotional tool for Company 2. The *Open-Source Production Pattern (OSPP) Document* is included once the garment file is downloaded.

The company has seen a low level of participation, but Participant CS201 believes there is significant value in investing in the open-source system. Participant CS201 states, "*I'm not bothered about it. I believe in this as a good promotion for us, and it was a spark for other things."* The participant believes that in the long term, this model will become a standard way to design and manufacture. Although Company 2 has not fully promoted the platform, it has the potential to support mainstream trends, including virtual worlds like the Metaverse. The building blocks of Company 2's open-source fashion system includes the following:

1. **Open-Source Production Patterns and digital material available**: Open-source production patterns and material will allow for open-source design development.
2. **Open-source design development:** Allows customers to be part of the design process by allowing them to create with open sources.
3. **Pre-order online platform:** Designs can be rendered into photorealistic images to be sold with instead of a physical product. Payment is made before producing the physical garment.
4. **Individualised body scan for a digital twin:** Having digital twin avatars will enable virtual fit.

Table 8.1 below demonstrates what Company 2 has achieved thus far in building an open-source fashion system.

Company 2's Current Open-Source System			
Digi-Physical Asset	Yes	No	Source
Digi-physical garments	X		In-house
Digi-physical trims	X		Outsourced– Free to download [Software Vendor B]'s collaborative platform ET

Digi-physical fabrics	X		In-house digitising of suppliers' fabrics
Smart contracts		X	Through [Software Vendor B]'s collaborative platform
Open-Source Platform	X		[Software Vendor B]'s collaborative platform
Auto grading/sizing software		X	Software provider– in progress.

Table 8.1 Company 2's current open-source system

The following sections discuss in further detail Company 2's progress in building a fully supported open-source system. The discussion includes:

1. Open-Source Platform – [Software Vendor B]'s collaborative platform
2. Open-Source Production Pattern (OSSP) – Production Ready Patterns
3. Digitising Fabrics
4. Co-Creation in Partnerships
5. Connected Production

8.8.1 Open-Source Platform– software vendor B's collaborative platform

For Company 2, the first step would be to create a space to host their open-source resources. Launched in 2018, [Software Vendor B]'s collaborative online platform offers a lite version of the software to view any supported [Software Vendor B] files without a licence. The interface is simplified, and designers and artists can use it to display, promote, and sell their digital designs. Additionally, major trims and hardware brands have contributed by providing free digital versions of trims for users to access. Participant CS204 states, *"So it's really getting more attention as a way I think to brand yourself, and for analogue companies to become digital."* It is important to note, [Software Vendor B]'s collaborative platform also consists of users utilising it as a marketplace; therefore, everything is not entirely free. It is up to the user to determine how the platform is utilised. Participant CS204 adds, *"…there's a lot of different styles where for me this is very hard to picture in real-time or in the physical world, but it's only in view only mode, so maybe it's not meant to."* Company 2's aim for the digital assets is to create practical, production-ready resources as opposed to only 'visualisations' for the digital world.

Currently, the open-source platform serves various purposes. Firstly, it is the main communication tool. The first design review for a client is carried out digitally on the platform. It allows clients to comment, interact, and view the 3D virtual garment. Secondly, the platform serves as Company 2's Open-Source Platform, housing their digital fabric libraries and digital patterns. Similar to the concept of *Sharewear,* which the original design studio explored, one can download the garment pattern and recreate their designs. Additionally, Company 2 encourages others to contribute to the library by developing new styles.

8.8.2 Open-Source Production Pattern (OSPP)–Production Ready Patterns

In 2021, the company released a PDF manual called *Open-Source Production Pattern (OSPP) Document* – which provides guidelines and technical specifications for the user to ensure patterns are ready for production (Company 2 literature, 2022). Additionally, the document includes rendering information to achieve the same effects such as lighting and camera position. Participant CS204 explains, *"There is this similarity running through all the patterns on the platform. There will be a bit more diversity in the patterns and aesthetics itself, but it will be built the same way, which is quite nice."* The manual aims to create standardisation of patterns for production.

8.8.3 Digitising fabrics

See section 8.4.3 Company 2's fabric digitalisation process.

8.8.4 Co-Creation in partnerships

The importance placed on the creative community and collaboration is what Participant CS204 and Participant CS201 find the most appealing about the possibility of an open-source fashion system. Participant CS204 states, *"…The customer also becomes part of the design process and can help develop the specific product they want."* The original *Sharewear* project raised another key element of creating collaborations and a variety of projects instead of a brand. The participants feel collaboration and a collective effort will scale open source.

8.8.5 Connected production

Using a pre-order system would allow for producing what is demanded. However, Company 2's open-source framework would need to consider the practicalities on how to achieve quick turnaround time for production to support a pre-order system. One solution would be to keep certain fabrics in stock. Company 2's digital printing partner has a delivery time of one week to Gothenburg. Participant CS201 explains,

> *Let's say you place an order of one garment, which might cost roughly €100 to produce. But if you place an order for 50 garments, then the price may be €50 for each piece. If you want a lower price, wait to place the production order until you sell 100 pieces on pre-order. If we can have a global reach for this, theoretically that wouldn't be a problem.*

A layer cutting machine would be essential for automating size grading and layout. Participant CS201 explains, *"There could be one continuous layer of cutting 50 pieces automatically, and someone sorting them. It would only be slightly more work compared to what we do now with mass production."* Participant CS201 predicts if AI generated designs are paired alongside ecommerce, the pre-order system, and automated grading, this would have a profound impact on brands. Participant CS201 explains,

> *This may have the potential of replacing what brands are doing today. They hire people to work with the distribution, marketing, and the design. The majority of the brands today, don't own or control their physical production. So, this is why I don't run a fashion brand any longer, but a factory.*

It is important to note production would remain physical. Company 2 is exploring digitisation and/or automation in production as the next area to transform.

8.9 Exploring Industry 4.0 in relation to an open-source fashion system

Exploring digital technologies is ongoing and crucial exercise at Company 2 as it continues to digitise areas of production. Despite the success of Company 2's technology integration, there are many more technologies to consider. Interestingly, other virtual technologies the participants mention align with the Industry 4.0 paradigm – including blockchain with smart contracts and artificial intelligence. This section discusses the developing virtual technologies Company 2 believes will impact the industry and to support an open-source fashion system:

- Blockchain Technology
- Artificial Intelligence
- Automation technology – Auto Grading System

8.9.1 Blockchain to support an open-source platform

If open-source resources are available for free to use and download, how to monetise and protect intellectual rights must be considered. Blockchain technology is suggested as one solution as it creates a trail of activity to authenticate the process and/or asset. In addition, automated contracts – known as smart contracts– can be assigned to a digital asset. According to Participant CS201, Software Vendor B is currently testing smart contracts within the open-source platform. Participant CS201 explains that some items are labelled as ‘original items’ and others as 'derived items'. For example, if Company 2 uploads a digital fabric file and it is downloaded, a link is generated to direct the user or future users to the previous or original digital asset. Participant CS201 explains,

> *Let’s say someone sells that for $5.00. You download it, rework it, and sell it again, the option for you to charge will start at $5.00. If you charge $8.00, then five of those would go to the originator through that smart contract distribution chain.*

Company 2 has built in smart contracts within their patterns to have accreditation for future use. Participant CS201 envisions attaching smart contracts to both a digital and physical design. Participant CS201 explains, *“If there can be an automatic transaction being forwarded to the originator, then the interest in publishing open-source design will explode.”* Participant CS201 believes this could radically transform the business of fashion, and states, *“That would change the whole industry dynamic from being an industry of 200 years of total secrecy of no one telling the other where they buy their buttons.”* This suggests the capability of an automated process to support reorders and pre-order sales.

Moreover, Participant CS201 is also seeing the application of blockchain and smart contracts to establish organisations – known as decentralised autonomous organisations (DAO). Participant CS201 defines DAO as *"Communities which are set up and linked to the blockchain."* Instead of a traditional model of a hierarchy with a board of directors, rules on how the organisation is set up are created collectively at the start of the blockchain. Participant CS201 further adds, "*With smart contracts one can then set rules for how wealth or financial resources are divided."*

8.9.2 Artificial Intelligence (AI)

In regard to AI, there is a high level of speculation about its potential impact on design and fashion business. Participant CS201 believes that AI could revolutionise how designers generate ideas by creating 3D virtual objects from textual input. This is an area currently being explored by 3D design software vendors. Participant CS201 explains, *"One of the underlying objectives of having this [Software Vendor B]'s collaborative platform where they ask users to upload different designs is to collect data.*" For AI to be effectively applied in garment design, a comprehensive database is essential. Participant CS201 states, *"I can't see why eventually it shouldn't happen that garment design could be also made by AI after only textual input."*

An example of the design and product development process starting from the point of virtualisation is a collaboration with AI project DALL·E – AI technology that generates images based on text. Participant CS201's previous business partner is working on a project with AI technology. An image was generated from a sentence: *"33 people for the most progressive digital fashion brand in the world visiting Paris wearing hyper-corrected clothes, bird theme"* (Open AI, 2021). The design and development team are working on interpreting the image into a digital pattern in 3D design software. Design development is then carried out to reach the desired outcome for a physical design to be produced and sold. The brand plans to have a costume maker create the physical samples.

8.9.3 Automation technology – Auto grading System

Pattern grading is the process of increasing or decreasing the size of the pattern to fit different sizes. The process is often carried out manually and considered a tedious task. Automating this process is highly technical requiring expertise in computer science. Avatars and 3D garments consist of a series of triangles to create a mesh.

The software measures the distances between the triangles. When replacing different size avatars, the software is able to calculate the distance of the new garment into the needed ratio for fit. Participant CS201 states,

> *So, all the size operations happen in the 3D object. Then it's flattened out and makes a working pattern where all the seams match together. That's one of the headaches of traditional grading, so this makes so much sense to me that this should replace these 1850s ideas of size grading.*

To allow for size customisation within the open-source framework, Company 2 is exploring an automatic grading system compatible with [Software Vendor B]. Through the advancement of grading technology, Participant CS201 feels this could replace the concept of sizing. If automation of size grading can be developed, the ability for mass size customisation could become reality. The participant sees a need for auto-grading to link digital assets to physical production. Participant CS201 states,

> *I see a need for this which is a growing sea of 3D garments which I assume are made by 3D artists who don't really have a clue about how a factory works. So, a lot of these things would take quite a lot of work to have them producible.*

Participant CS201 sees the possibility for users to choose an avatar, a garment file, and design details such as trims within [Software Vendor B]'s collaborative platform without having prior pattern knowledge. Participant CS201 states, *“The fantastic thing here is that you never see the 2D pattern, but it exists in the background.”* Participant CS204 comments, *“It kind of becomes more like a game of assembly.”*

Nevertheless, this raises questions around the user friendliness of the 3D design software for those without garment construction knowledge. Participant CS201 states, *“For being a CAD software, it's fairly easy to use, but it's still quite complex so far, and you need to know a lot about garment making to be able to handle it.”* In the participant’s opinion, learning the software is available and accessible through YouTube tutorials. Participant CS201 states, *“I mean everything is getting easier and more accessible. So, loads of people would do these things.”*

8.10 Final thoughts

Company 2 was designed to be unconventional in response to the traditional fashion industry. A strong focus and personal conviction to change processes is evident amongst the participants. Throughout the case study conceptualising a digi-physical microfactory proves challenging, as it is ahead of its time. The characteristics of the digi-physical blur as the lines between digital and physical realms, reflecting principles of Industry 4.0. Company 2 exemplifies a bespoke and flexible approach to manufacturing that benefits both the business and its individual clients. With numerous projects and collaborations occurring simultaneously, establishing a linear business structure is challenging. However, as a pioneer in the industry, the process will be redefined.

Company 2 serves as a practical example of how digital tools are transforming and challenging traditional garment design, product development, and manufacturing processes. The excitement of possibilities of new business models and products is what makes Company 2 intriguing. However, as these technologies evolve, there is a transitional period between futuristic visions and everyday realities. Despite the successful adoption and integration of virtual solutions, many of Company 2's processes remain traditional. This case study underscores the limitations and practical considerations necessary for implementing new systems such as open source and virtual garment/apparel production. Distinguishing between technological ideals and practical realities needs to be objectively considered.

Chapter 9: Case Study 3 Report

9.0 Introduction to Chapter 9 — Case Study 3

As brands and retailers adopt 3D design technology, their suppliers are compelled to seek supporting virtual solutions. This case study report explores the practicality of virtualisation from a supplier's perspective. Case study 3 makes for an interesting subject to examine the impact of digital transformation and virtualisation from the perspective of a denim mill. Unlike the first two case studies, Company 3 has not yet established a digital transformation journey but is exploring what this means and looks like for the organisation. Case study 3 aims to capture the initial conversations around planning, attitudes towards digital technologies, and potential challenges and barriers. This chapter is outlined as follows:

- About Company 3
- The art and science of denim
- COVID-19 pandemic – a catalyst for digital transformation
- Product profiles
- Digital transformation – initial plan to introduce 3D design software
- Progress of digital transformation
- Envisioning a digitally transformed Company 3
- Drivers of digital transformation
- Barriers/challenges of digital transformation
- Concerns around virtualising denim product development
- Identifying and selecting digital technologies
- Plan of action: next steps
- Final thoughts

The next section introduces Company 3, providing context for this chapter's discussion.

9.1 About Company 3

Company 3's head office is based in Greensboro, North Carolina, USA, and it operates as one of seven subsidiaries under the [Parent Company] umbrella. As a denim mill, the company also produces yarn at their two production facilities in

Mexico. Both the Mexico and China facilities include dyeing, weaving, and finishing capabilities, with a combined capacity of 92 million yards (approx. 28 million metres) of denim (Denim 101 Presentation, 2023). Company 3 was founded in 1891 and has been manufacturing denim since 1896. Known as ‘The American Denim Manufacturer’, the company supplied the most denim to workwear and denim manufacturers globally in the early 1900s (Abrego, 2018, p.515) and continues to supply to some of the most established jean brands. Company 3 has a history of denim innovation in manufacturing processes and textile production. For example, the process of rope dyeing indigo was invented at Company 3, and it was the first to use shuttleless looms in denim production. Today, the Company continues to be a leader of innovation. Their *Zero Liquid Discharge* water treatment system saves up to 100 million gallons of water a year (Company Website, 2022). With a long history of innovation and high quality has earned Company 3 a respectable global reputation. Participant CS306 states,

> *I think we're unique just from our history and everything we offer. Coming off the [trade] show last week in New York, you could tell we have a presence. I'm proud to say that we're one of the first stops for every customer. Our booth is always busy.*

Company 3’s premium label of selvage denim has a deep connection to the mill and is highly regarded amongst *‘denim heads’* – connoisseurs of denim. Selvage denim is considered 'premium' and is more expensive to produce. A selvage, also known as selvage edge, is defined as *“a narrow tightly woven band on either edge of fabric parallel to the warp that prevents fabric from ravelling”* (Company 3 Materials, 2013, p.6). The selvedge edge is durable and can be used in making jeans.

Unfortunately, in 2017 Company 3 made the decision to close its Greensboro mill, the last selvage denim mill in the US, and discontinue the premium label (Shuck, 2018). As a result, many thought Company 3 was no longer manufacturing denim. Despite the strong reputation of the premium label, the sales did not match the demand. Participant CS3017 comments, *“We don't sell B2C, but obviously when we do, those numbers go way up. But when we had a physical store, those numbers didn't match. It's very contradicting.”* Currently the company is rebranding as there is a high level of confusion around the brand as terminologies and viewpoints have been added throughout the years. Participant CS3017 states, *“Now we're trying to rip off the Band-Aids and saying OK, this is still us. We're just doing things a little differently, but we're keeping to these core values.”*

9.1.1 Not a garment manufacturer, a textile mill

Company 3 operates Business to Business (B2B), supplying denim to garment brands and manufacturers. This requires a different sales strategy compared to Business to Consumer (B2C). According to Participant CS303, B2B is considered *"behind the scenes"* of the industry and is not as straightforward as B2C, especially in regard to visual marketing. Participant CS3017 also agrees and comments,

> *Buyers already know what they want. If they don't, they have an idea. But consumers really don't know what they want until you tell them…They can easily be convinced a product is worth buying if it has the right story behind it. Buyers can be, but they're more running a business and focused on numbers.*

A different approach to storytelling is required in B2C selling. Participant CS3017 states, *“It’s hey, you need this product because your consumer is wanting this.”* The head office features a denim showroom displaying the latest season of washes in finished jeans in a variety of silhouettes. The garments are presented with Company 3’s hang tag to showcase a finished product. However, this can be misleading as it gives the impression that Company 3 designs full packaged garments. As discussed previously, Company 3’s identity can be confusing since it is easy to forget that the company is a fabric mill – *not* a garment manufacturer. Participant CS306 explains,

> *Which can get confusing a lot of times… Because we emphasise the garments, we want them to think, 'oh, that could go immediately into our store'. The fit, the fabric, the stitching, the trim, that's the way we approach it.*

After speaking with both the product development and design teams, they emphasised the importance of having the denim in garment form for clients to *‘spur their creative process’*. The sales team often works with a variety of roles, such as merchants, sourcing teams, or those in charge of creating the tech packs for a garment. Participant CS307 explains,

> *From a visual standpoint, it's easier for customers who are not design minded to conceptualise what our denim can do when it's in a garment. You have a header or legs, but you can see about 4-6 inches of it. But actually, seeing how it moves, such as the open weave textures, it's a lot different than what you imagine.*

Participant CS306 explains this is how some designers work, and adds, *"There are many times we'll be sitting with designers, and they'll immediately take our jeans and run for the closet to put them on."* Displaying denim in garment form is not common industry practice, but the participants consider the physical garments as a competitive advantage. Participant CS306 states, *"I don't think it's very effective [without garments] ...but I think they really appreciate what we're doing and what we put into it...it's a way for us to differentiate ourselves."* Moreover, as a supplier, it is important to stay up to date with garment trends and have the ability to understand and translate these trends to their clients. Participant CS304 states,

> *We almost act as a brand in the sense we have to speak to a brand the way they understand…how do we speak the language of the brand, not speak the language of a mill? I've seen both sides. I was also at a point in my career where I understood mill lingo and not brand lingo, and there's just a mess.*

Interestingly, the team finds their clients inquiring about purchasing the garment samples. Participant CS306 explains, *"There are a lot of people that still ask, 'Where can I buy the jeans?'... I wish we did sell our jeans in stores, but that's not the way it is."* Starting a garment line under their own well-known premium label has been in discussion; however, this would be problematic. Participant CS3011 states, *"We would be in competition with our own customers right now."*

9.1.2 Sales Process

Company 3 heavily relies on trade shows, individual visits to companies, and online sales presentations. The sales team presents the denim with digital presentation platform Prezi along with the finished jeans, headers, and legs. The sales team leaves what they call 'product profiles' – a document containing all the specifications and certifications of the denim. After the presentation, the next steps in the sales process include:

1. The customer keeps the headers and legs as references and may request other samples.
2. The customer will request sample yardage.
3. The customer places the order.

9.2 The art and science of denim

Denim product creation is both an art and science. It demands deep expertise in every stage from cotton procurement, dyeing, weaving, and final garment production. The technical manufacturing process is complex, as numerous variables can influence the final outcome. Each stage of the process requires precision to achieve the desired shade and texture of denim. Participant CS307 explains,

> *It's really hard to replicate the same colour. That's where all of the fun quality assurance comes in. If we can hit the same colour, fantastic. If we've made a mistake, made a new colour, and we like it, we just have to figure out different ways to do it.*

For high-end clients, accuracy is crucial. Participant CS3010 states, *“They can be very picky. I'm not saying that negatively, but they're extremely specific in what they want and what they're trying to achieve.”* Factors such as yarn size, slope pattern, and weave tension are carefully considered. In addition, consistency is highly important. Participant CS3010 states,

> *The big creative process is where you say, we'll see what comes out. But the real tricky part is when you have the recipe of the wash, the finished garment, the stretch level that works for your customer. The colour and the hand feel need to be consistent.*

The client will need to replicate the same look for hundreds or even thousands of units within their wash facilities. Many of Company 3's clients use the same fabric from season to season, as it is easier to reuse a popular fabric than to ask for a new development. Therefore, a client might only request to develop a new wash for a collection or season.

One main challenge of producing and selling denim is the wash stage. Denim is sold unwashed and is sent to the garment manufacturer. Once the final garments are sewn, they will ‘go to laundry’ – or to be washed down for the desired effect.

Participant CS305 states, *"Denim can be washed in 400 different ways. That's the beauty of denim and indigo. It's engineered to chip off and wash down. It's a different animal."* Creating the garment before undergoing the wash process gives the finished worn look associated with denim. Participant CS3010 explains,

> *If we were washing the fabric and sending it to our customers, you wouldn't see those highs and lows that happen at the seam on the side of the garment, at the pocket, or at the hem. That only can happen if you wash a finished garment.*

Since Company 3 only produces the fabric, it does not control the wash process, which is carried out at separate laundry facilities often in different countries. Consequently, the final appearance and texture of the denim can vary due to differences in chemicals, water, and washing techniques. Participant CS3010 explains,

> *[Clients] come back to us and say, 'Hey, the garment that I saw in your showroom was very soft and very clean. I washed it at my factory in Vietnam or Bangladesh. It came back, and it's really not as soft and a lot hairier than I thought'.*

The washed fabric is then returned to the brand or retailer, which can result in losing a client. Participant CS3012 explains, *"These guys say well I don't think the fabric is working, but it's not the fabric's fault! They can say it's a fabric issue rather than a wash issue."* In Participant CS3012's opinion, this issue stems from a lack of knowledge about denim. In such cases, the product development and quality control teams guide clients in resolving these issues.

9.2.1 Designing denim

In denim product development, two key processes are involved: 1) the design process and 2) production. For this study, participants from both the design and product development teams are grouped together, as the roles are closely intertwined. The team comprises five designers located globally: the Senior Merchandiser/Product Developer and Product Developer Assistant in Greensboro, two designers in New York, and one designer in Hong Kong.

New collections are released every six months, and each designer is responsible for designing denim for their assigned client. Participant CS304 states, *“I would say each member has unique abilities, and I think that's what makes this team so amazing…there's a lot of little details in between all of it and what goes into it.”* The team conducts market research by visiting mass market to high-end retailers to observe what is selling or where there is a gap in the product offering. Inspiration comes from a variety of sources. Participant CS304 states,

> *Because we're not a brand, you can look into other markets for inspiration and see how that can influence denim. I always love looking at non-denim brands to see what they're doing and see how we can incorporate anything there.*

The designers maintain constant communication with their customers to gather feedback. Participant CS305 explains it is a *"give and take"* relationship, and states, *“We lead the industry, but then the customers also ask for things. It's kind of a two-way street.”* During their seasonal kick-off meeting, the team presents ideas, inspiration, market trends, and visuals. They collaborate to develop concepts for each collection and determine how the line will be merchandised. Participant CS304 states, *“Instead of just rolling out 40 fabrics, we really like to merchandise it as if we are a brand. This is our collection, and the inspiration behind. Like little capsules of fabrics.”* The team then narrows down ideas and assesses what is feasible for each mill. Participant CS304 also believes it is part of the design team's responsibility to push for innovation while working closely with the manufacturing team, which forces on ensuring efficiency. Participant CS304 explains,

> *Not to say that we want to throw the mill upside down, but sometimes you have to push a little bit to get something that's innovative and new. Something that your customer didn't realise that they wanted. Then they think this is really cool, and it becomes the next big fabric.*

The information is compiled into a fabric brief and uploaded to a system, which then notifies the product developing and manufacturing team to develop the fabric. The design team creates a chart to track the product life cycle, including stages such as fabric development, garment creation, and washing. This information is added into the ‘product profiles’, which will be discussed in Section 9.4 Product profiles.

9.2.2 Product development process

The process of creating denim is discussed to provide context for later discussions around virtual technologies. Steps in denim product development process include:

1. Once the design team uploads idea briefs into the Product Development Tracker System (online), the product development team decides how to approach development and trial sample runs. The samples will be 'rigid' – meaning the material/garment has not been washed.
2. Samples are sent to the design team for approval or to request further development. The teams in Greensboro, Hong Kong, and New York will receive 'four legs', also called evaluation legs (See Figure 9.1) and evaluate the denim samples. The number of trials are numerous.
3. Once the four legs are approved by the design team, approximately 5,000 yards (around 4,572 metres) of the selected denim will be produced.
4. Once approved, the denim is converted into a 'style' – meaning the legs are turned into headers to help clients to visualise how the fabric washes down. The first rinse involves a quick run through water to make the denim easier to wear with minimal colour change. Stones may be added during the wash process to create a 'stonewash' effect. The final rinse is completed using Company 3’s own chemical treatment.
5. The design teams receive and evaluate the '7 Step Leg'– rigid samples including seven different wash treatments. Although the fabric remains rigid or stiff, even with added stretch, the material is not ready to wear. However, garments are created at this stage because the stiffness of the fabric makes it easier to stitch together.
6. Once the denim is approved, 5 garments will be made per style. The offices in Los Angeles, Dallas, and Greensboro receive garment samples. The Hong Kong office has its own sample production suppliers.
7. Final washes and garments are selected, and product profiles are updated.

Figure 9.1 Denim legs and headers

9.3 COVID-19 pandemic– a catalyst for digital transformation

Many participants state that the 2020 COVID-19 pandemic was the initial push Company 3 needed to *"jump start"* exploring digital solutions. Due to the travel ban, Company 3 could not visit customers or attend trade shows. Participant CS301 states, *"It's not that you didn't want to travel. You couldn't travel. You couldn't get into a lot of countries…I think that the pandemic definitely accelerated the need for it."* Trade shows are crucial for Company 3, as selling cycles are based around trade shows, and sales heavily rely on in-person selling as discussed previously. Participant CS3016 states, *"When that went away physically, we had to pivot and figure out how to show them fabric digitally because they were still doing virtual trade shows."* For the next three years, there would be no physical trade shows. Participant CS3016 states, *"It was the pain of everybody's existence. Has anyone ever done it before? And so how do you video it and showcase it?"*

The sales team carried out their presentations via video conferencing tools and digital product profiles. Virtual presentation tool Prezi proved useful as a communication tool to engage clients. Participant CS301 shares, *"It's very low tech, but what that let customers do was to dial in and say OKAY, this looks interesting. Send me a sample of that. So, we were able to stay in touch with our customers when we couldn't travel."*

In addition, the product development and design teams manoeuvred quickly as the New York and Hong Kong offices were closed. Consequently, the process of reviewing fabric shifted from a daily to a weekly task. Participant CS306 states,

> *We physically had to make the investment to ship to all homes. We would all have the same panels in front of us and would look at everything on the phone together…There was just a lot of denim in people's homes.*

Participant CS3016 explains it was not ideal, but it had to be done. The participant also believes that if the panels had been digital, there would not have been the expense of shipping fabric samples during lockdown – nor the waste, even though the samples were recycled.

Despite the challenges of COVID-19 pandemic, Company 3 and their clients found many benefits of adapting to the new way of working. With no other choice, customers welcomed the virtual meetings, proving that conducting business virtually is possible in their sector of the industry. Participant CS308 explains,

> *I don't think our customers ever would have accepted a digital representation of a fabric because they're so used to having the fabric in their hand. We've bent over backwards for decades to do what we can to get samples to them quickly. Without the world just completely shutting down, I think that would have been a really difficult transition for them.*

Some of Company 3's clients began questioning if physical meetings are even necessary. Participant CS208 states, *"...It was like 'you don't need to come to my office and throw all your samples on my table. You can walk me through your presentation with pictures'."* However, the participant strongly emphasises that virtual samples do not replace the need for *all* physical samples.

9.4 Product profiles

Prior to the COVID-19 pandemic, the head office held rooms full of fabric for samples for the teams to reference, and physical samples were provided to the customer for their reference. Denim specifications such as weight, width, blend, etc., were emailed to clients. However, this process became problematic during the pandemic when the office was closed. To effectively communicate products to clients, the teams developed 'product profiles'– digital documents containing relevant details of a product, such as certifications and fabric specifications. Post-pandemic, the product profiles continue to prove useful. Participant CS305 states, *"The pandemic lit a flame* *under us to really get this digital platform available to customers… It helped during the pandemic, but now it has just become really versatile afterwards to help our physical sales."* The steps in the product profile process are as follows:

1. Photograph all fabrics and garments.
2. Place the photographs into an InDesign template.
3. Gather product information and place it in the template.
4. Share final PDFs via SharePoint for internal collaboration, or to be emailed or printed for clients.

Currently there are over 300 product profile documents and managed by one person.

9.4.1 Benefits of product profiles

The product profiles serve many purposes, including organising products for internal teams to find information on a specific product and serves as a 'leave behind' – a reference for clients of interested products after a sales presentation. Participant CS3016 states, *"If you're showing a client 20 fabrics and they have narrowed it down to five, well here's the information on those five."* Participant CS3012 is seeing a change in buying habits of customers in the last few years as a new generation of buyers emerge along with the older generation. Participant CS3012 states,

> *You also have a generation where people study one thing, and they don't have a broader understanding of what they're doing with the product. So, you need to spoon feed a lot of the information. You also need to lead them to a point where a decision is made in an easier way.*

Participant CS3012 suggests that attention spans are short because *"we live in the digital world…You have to skim through the noise and make your decision."* As a result, the sales team has to 'fight' to keep clients engaged, and the product profiles help achieve this. In addition, the designers work closely with the sales and marketing teams. Participant CS304 states, *"The designer creates the product. They are so close to it, and passionate about it. They have all the lingo and the story. We have to remain very close to marketing."* Product profiles are essential tools for communicating design intent across functional teams and explaining the technicality of denim in a general way. Participant CS304 states, *"How do you get it to be not so technical but explain something in a way that it's very understandable to* *anybody…the product profiles have the same language embedded as the collection catalogue that we're creating in the Prezi."* These sales tools are distributed amongst clients, exhibited at trade shows, and included in the press. Participant CS304 states, *"Those tools are really our pride and joy."* Therefore, capturing the fabric details in high-quality photographs is crucial.

9.4.2 Challenges of the Product Profiles

Despite the benefits mentioned above, there are many challenges with utilising Prezi presentations and digital product profiles. Both require a significant amount of time and labour to create and manage. Data is compiled manually on each product from a variety of teams (e.g., edited photos from marketing and branding from suppliers). The managing participant often has to chase up individuals for the information or updates, such as when a product undergoes a wash or gains a certification.

Moreover, IT issues were mentioned, similar to those experienced during the COVID-19 pandemic. For instance, the resolution quality of Prezi presentations often varied based on internet connection. High-resolution photos could down the presentation, promoting the team to spend significant time reducing image sizes. Many participants expressed feeling frustrated by these technical difficulties. Participant CS306 states, *"Clearly, we adapted, and did what we had to do. We still built these platforms for that presentation. I hope it changes to something better that does help show the fabrics clearer."* Many participants believe the product profiles should be the priority focus on the initial step in digital transformation. This, however, raises questions about what other digital solutions should be considered next.

9.5 Digital transformation – initial plan

The initial discussions regarding Company 3's digital transformation including exploring the implementation of 3D design software. In early 2022, the VP of Marketing and an internal team began investigating relevant technologies. The team met with 10-15 different software vendors, ranging from 3D design software to 3D virtual fabric scanning solutions, and consulted garment manufacturers experienced in 3D design software. The investigation required significant time to understand industry trends in virtual solutions and their applicability to the company. Participant CS309 explains, *"Then basically the time, money, and resources that would be* *needed to go into it to ultimately make it run."* From these discussions, two primary objectives emerged for why Company 3, a textile mill, is considering 3D design technologies and virtual solutions:

- Objective 1– The customer
- Objective 2– Internal benefits

9.5.1 Objective 1– The customer

The discussion about 3D design software was initiated by one of Company 3's largest account holders – a reputable retailer undertaking a company-wide digital initiative. The initiative demands the full integration of 3D digital sampling within design teams to address fit and design issues. Therefore, this would eliminate the need for unnecessary physical samples. This initiative also extends to the retailer's suppliers, including Company 3, who are required to adopt 3D design software. Participant CS309 explains,

> *Basically, the way they proposed it was the first sample would be done based on their guidance with product packets and physical samples to match sent to them. Any tweaks would be done in 3D fashion design software.*

Three digital garment samples were estimated to be sufficient to confirm the wash of the jeans before producing a physical sample. The sales team at Company 3 would work closely with the garment supplier, who would carry out the full design, product development, and production of garments. This would require Company 3 to gain a deeper understanding of product development, effectively removing the retailer from the process. Participant CS209 explains,

> *We would handle the fabric directly with the garment manufacturer. They would manufacture it, and then we would buy it back from them. Then sell it to our customer, so it would be a full package. All they deal with is sourcing the garments.*

The team considered hiring two garment designers: (x1) technical and (x1) fashion designer. The use of 3D design software would be for garment sampling and to communicate designs with the brand or retailer and their garment manufacturer. However, the retailer's plan was paused around the end of 2022, which put

Company 3’s plan on hold. During the visit to the main office in Spring 2023, Participant CS309 noted that the retailer had resumed sending follow-up emails.

9.5.2 Objective 2– Internal benefit

Objective 1 was customer specific and planned as a pilot project; however, it was an opportunity to begin considering potential internal benefits alongside the project. Participant CS309 states, *“It seemed natural to start to digitise some of our own things for our core business, which would be almost an accessory to this.”* The short-term and long-term goals include:

- **Short term**– develop an online portal or app to house a digital fabric library, allowing designers and clients to view digital fabric swatches at any time.
- **Long term**– Provide a virtual experience for clients, such as a platform in the Metaverse or a virtual showroom.

As a textile mill, having a digital fabric library to showcase the range of washes would be highly beneficial. Many participants explain it is physically impossible to carry *all* denim washes to a sales meeting. Clients often request wash that has not been brought to the meeting. As a result, the client must place an order for the headers and wait. A digital fabric library could be a solution by allowing clients to view and select options directly. Participant CS309 explains, *“They can just click. They don't have to rely on a salesperson or customer service to shoot this over email. They could basically go shopping and see what they wanted.”*

The digital fabric library would eventually replace the product profiles and reduce the number of physical samples and documents presented in sales meetings. Other potential benefits of a 3D virtual fabric library mentioned include:

- Clients have access to information regardless of location and time zones to browse or reference a fabric style.
- Digital fabric files will be available to download and import into 3D design software.
- 3D digital garments provide an interactive experience compared to 2D flat images of garments benefiting clients and the sales and design teams.
- This could streamline the decision-making process and potentially increase sales.

9.5.3 The feasibility of both drivers– initial plan

Both objectives, however, presented a series of challenges before the plan could be executed, such as:

1. ***Objective 1:*** *A full garment package, including design, production, and finished denim in a variety of garment styles to be presented to the retailer.* Challenges of Objective 1:
    - Company 3 is not a garment manufacturer. Can this request be fulfilled by Company 3, and should the company be responsible for carrying it out?
    - Who will be responsible for ensuring the process is executed and achieved?
2. ***Objective 2:*** *Digital fabric swatches to be utilised in their 3D design software and for clients to review anytime.* Challenges of Objective 2:
    - Where will the digital fabric library be housed, and what will it include?
    - Who will oversee and manage the digital asset library?
    - What security measures and access controls will be implemented to protect intellectual property?
    - Who will carry out the digitising/scanning physical fabric process?
    - What equipment is required to support digitising fabrics?
    - What internal capabilities are available for this task, and if lacking, which third parties can assist?
    - What are the initial start-up and ongoing maintenance costs?

Initially, the team planned to carry out some of the photography internally while outsourcing colour matching software to a third party. However, there is currently a lack of internal capabilities for digitising the fabric.

9.6 Progress of digital transformation

With the unexpected leave of the VP of Marketing in September 2022, Company 3's digital transformation plan came to a standstill. No further action has been carried out since. Conversations around Company 3's digital transformation plan resumed during the visit to the head office. The participants quickly realised the need to start again with the research stage and answering questions such as:

- Where do we start?
- Where are these areas of implementation of digital technologies?
- What does the process of implementation involve?
- What are the software or virtual technologies to invest in?
- Do we have the internal capabilities (e.g. skills, staff, time, hardware, etc)
- What are the start-up and maintenance costs?

Participant CS301explains, *"We have to educate ourselves on what's available, what the benefits are, and what the pros and cons are…So I believe it's needed, and we're going to invest time and money to get into that space."* However, what is the path or how to define digital transformation for Company 3 remains yet to be defined. Before leaving Company 3, the VP of Marketing left a budget plan (See Table 9.1 below).

Start-up Budget for Digital Transformation– 2023	
Expense	**Amount**
2023 calendar year + nominal fee for virtual fabric scanning	$3,000
Equipment to start	$25,000
One year subscription for chosen 3D design software	$24,000
Total	**$52,000**
Note: budget does not include recurring expense for scanning fabrics.	

Table 9.1 2023 digital transformation budget

Despite the uncertainty and challenges that face Company 3, the respondents have a positive outlook towards establishing a digital path.

9.7 Envisioning a digitally transformed Company 3

All the participants strongly agreed that digital transformation is essential for the company to avoid being left behind as the industry moves towards virtualisation. Participant CS301 states, "*It's definitely what needs to be done. Especially with how cut-and-sew and our customers are moving from a design perspective. We don't want to be in a position where we're late to the game."* Participant CS301 feels that

Company 3's rate of undergoing digital transformation is by no means fast, but states, “*It's just going to take time. We've got a lot of fabric.130 years worth of fabric.”*

Despite Company 3 being at the early stages of their digital transformation journey, participants shared their vision of how Company 3 might look once the transformation is complete. They identified three key areas that could be impacted:

Internal business

- The physical office space will be smaller, and less cluttered without *“stacks of denim all over the place.”* More people will work remotely from their chosen location.
- Be more ‘nimble', 'efficient', and 'flexible’ to clients’ demand.
- Digital processes will replace analogue methods to save time, such as data entry and written receipts at tradeshows.

The sales team

- Opens new communication avenues and improves communication for clients.
- Digital fabrics and assets will offer added value by showcasing more of Company 3’s capabilities during sales presentations.
- Adds value to the brand image by demonstrating forward-thinking and proactive using new technology.
- A digital library with a search and filter engine would improve the customer experience by allowing clients to easily narrow down their needs and preferences for products.

Manufacturing

- Allow unrestricted fabric innovation through scale, price points, or geographical areas of production.
- Support more collaboration and communication between the garment manufacturer and fabric mill on product needs.
- Data analytics to track the behaviour to predict what fabrics to create to support less waste and more efficiency.

9.8 Drivers of digital transformation

In a discussion with participants about why Company 3 has decided to undergo digital transformation, participants discuss two main drivers: 1) competitive advantages – to sustain business and 2) to meet customer's needs and demands.

9.8.1 Competitive Advantage – to sustain business

As discussed previously, participants feel digital transformation is necessary to stay competitive in the market, to respond to digital demands, and to overcome the challenges in the industry. Digital transformation and tools such as 3D design technologies have been identified as key areas of focus for the company moving forward. There is a unified agreement that digital transformation needs to happen, and the message is clear coming from the top. Participant CS3012 states,

> *I hear Participant CS301. He's got confidence in us and is investing in us to be ready for what's coming. You need to have a long-distance view to see enough ahead of what the future is going to bring. Technology? Efficiency? Sustainability? Absolutely.*

Participant CS3016 believes Company 3 wants to be a leader in the industry for innovation both in product and digital. Participant CS301 also states, *"There's a big focus on working smarter, not harder using new technologies, and not being stuck in the past…We definitely want to be involved."*

In addition, some participants discuss that change is inevitable as a new generation enters the workforce. Participant CS3010 explains, *"The new generation coming out of school, that's how they learn to work. So, the older generation, like me, within 10 years won't be there anymore. There's no choice. It's happening whether we agree or not."* Participant CS3012 also mentions that the new generation of buyers align with values of the present times, and states, *"Not like boomers who didn't care about polyester or how much their car was polluting. Now you have a new generation of buyers who have been more informed. You have a new generation of consumers."*

By undergoing digital transformation some participants feel it will allow Company 3 to stay competitive within the marketplace. Participant CS305 states, "*We're not the cheapest mill out there. I think having a tool that has all of these bells and whistles to show different washes, will create more value in terms of a brand's perspective."*

Because Company 3's product is more expensive than its competitors, having digital assets and tools would create more brand value to justify higher prices.

Participants mention other long-term benefits of digital tools such as enabling business endeavours. For example, reaching countries where there is no sales representation. In addition, if similar events were to occur again, business would be able to continue virtually. Participant CS307 explains, *"I feel like moving into that in terms of fabric being able to do something as quickly would be fantastic. Because post pandemic we've kind of learned you may have to do that you may not have another option."*

Responses are mixed in regard to participants seeing competitors undergoing digital transformation. Participant CS304 states, *"Our competitors are using technology and digitising. Now how well they're doing it and in depth, I couldn't tell you."* Participant CS309 discusses seeing one or two competitors offering a digital fabric library that is accessible without a sales representative. Participant CS3017 watches competitors' social media content, and there is a low level of promotion around digital solutions. Also, the participants are not seeing competitors offer digital scans of fabric at trade shows. Other participants, however, are seeing their competitors invest in digital capabilities specifically in areas of corporate business, sales, and product development. Participant CS309 states, *"... I know that there are other mills and companies that have a digital presence. We try very hard to get better on social media and on the web where everybody is accessing."* In a previous role, Participant CS304 has encountered mills digitising fabrics and including QR codes attached to garments, which would link to a photo of the garment and product details.

In regard to the general industry, Participant CS301 believes that the drive for digital transformation will be accelerated by the need for quicker turnarounds and time savings during the development calendar. Participant CS309 adds that the demand to move faster to meet clients and consumer expectations is a key factor. For the textile industry and Company 3, development calendars are 'aggressive', and a reason to seek digital solutions. Participant CS301 explains,

> *If somebody can get them a swatch 2 days faster than I can, they've got an advantage because people make decisions in the moment…when you're losing time and money, shipping samples all*

> *over the world to get people to approve them, you can't respond as quickly.*

Participants suggest if they could display digital fabric swatches digitally, it would allow the teams to be more responsive and reduce courier expenses. In Participant CS301's opinion, cost and time savings are the main drivers to invest in digital technologies. Participant CS301 states, *"I think it's very cool, but it has to have an economic reason for people to do it, and there's got to be tangible benefit. I think there is."*

9.8.2 Customer's needs and demands

Some participants have observed that their clients are adopting 3D design technologies within their garment design process. Additionally, some clients are requesting digital fabric swatches, virtual showrooms, or digital technology solutions. Participant CS306 feels that Company 3 is being forced to undergo digital transformation, and states, *"Our brands are making us do it…They're always going to be at the forefront of what's required."* Having digital capabilities is almost a requirement to conduct business. Participant CS301 states,

> *[Large Retailer] said, 'hey to do business with us, you have to have this software'. It's more about digital sizing and things of that nature… There's certain types of computer programs they want you to have just to do business with them.*

9.9 Barriers and challenges of digital transformation

Participants also raised several concerns in regard to digital transformation – such as a lack of trust in technology. Given the complex nature of denim production, many participants feel that certain processes may not be digitised with the current technologies on the market. Discussions with the participants highlighted various potential barriers and challenges, such as:

- Low technology adopter – outdated technology
- Hesitation, uncertainty, and resistance
- High financial and resource investment
- Intellectual rights and privacy
- Expectations of technology

The following sections will discuss each of these points in further detail.

9.9.1 Low technology adopter – outdated technology

Despite some clients requesting virtual solutions, Participant CS301 feels that such technologies are not yet widely adopted within the textile sector. The participant states, *"I think it will become more common over the next couple of years…A lot of people are talking about it, but not a lot of people are doing it."* Many participants also note that it is difficult to know what their competitors are doing as they are 'secretive'. Participant CS3010 states, *"Everybody tends to keep their game close to their chest…"* Some feel that the companies who are adopting virtual solutions are the 'real innovators'. Participant CS301 explains,

> *At this point, I think anybody who's getting involved in this would definitely be more cutting edge and leading the way…They're either going to be an early adopter, or they want somebody else to go out, prove the technology, and do the legwork for them. Once there's a leader, whether it's a program or something else, they'll jump on board quickly.*

Interestingly, some participants feel Company 3 will not be a leader in adopting virtual technologies. Participant CS306 states, "*To be honest we'll just be a follower. We'll be at the tail end of people already doing it if we're not doing it now. We're just catching up to the competition."* Participant CS301 also alludes Company 3 will not be an innovator, and states, **"***We're not the most technical savvy company. While we've made some pretty big improvements in the last couple of years, we're not where we need to be."* The acceptance of new technology is a slow process at Company 3. For example, when replacing emails with Microsoft SharePoint, Participant CS3011 states, *"Yeah, the learning curve…that took us well over a year to get people comfortable and on board."* This is to be expected, as the tactile element of textiles plays a crucial role in B2B sales. During the COVID-19 pandemic, Company 3 turned to Prezi as their main presentation tool. Participant CS301 notes, *"It's nothing that's super high tech, but for our industry it was pretty high tech."* Traditionally, sales representatives carry physical samples in a large suitcase to present to clients. Replicating the same experience virtually poses a significant challenge. Participant CS3011 states, *"It's a bigger challenge to go digital when it's*

B2B instead of B2C." A main challenge Company 3 might find is updating their general IT infrastructure to support a strong digital foundation for digital transformation.

Participant CS3010 states, *"So until someone says you have to do it, I think we'll just continue to do what we do until we're told to. I wish we would take more of an initiative."* They provide an example from the 1990s when the industry was required to test fabrics for harmful chemicals. Major brands were forced to comply. Interestingly, Participant CS3010 also believes that an external expert might be required to drive change within Company 3, stating, *"I don't think it would ever be an initiative that comes from me or [upper management]. They will need to say here it is."*

9.9.2 Hesitation and resistance towards digital transformation

Both Company 3 and their clients are pushing each other to adopt virtual technologies; however, there is hesitation on who will make the decision first. Participant CS3011 states, *"I have noticed between us and our customer they'll do it if we'll do it– or if we'll do it, they'll do it. Or what are you guys doing? What works for you?"* Interestingly, the sales team is fully on board with implementing 3D design technologies and pushing the digital transformation initiative forward. Participant CS309 states,

> *I think everyone on the sales team would probably agree that if we had our whole fabric library digitised, it would be a benefit. I think that would definitely not be customer specific. It would be across the board for something like a product package.*

The management team, however, is more cautious. Participant CS303 states, *"It's because they don't have to worry about where the money comes from."* Participant CS302 agrees and adds, *"…or managing the time to do it."* In addition, some participants feel certain individuals are not eager to adopt new technologies, such as older employees. Participant CS301 states, *"You're not going to be able to reach them because they don't care. They don't want to learn new technology."*

Additionally, some participants feel that undergoing digital transformation will be more challenging for designers, as they are not used to working with technology.

Participant CS307 states,

> *I don't know if we'll ever fully get to digital only because so many designers have gone through their entire lives learning by having something right there. So much of it is the feel and actually being able to touch and mess with the product.*

Participant CS304 is aware of the uptake of 3D design software in the industry and believes the newer generation will design in this way. Participant CS304 states, *"That's a language they're going to speak. Maybe the designers in their roles now, they didn't learn that way. We didn't learn. It's very important to keep in mind."* In regard to the level of motivation to learn new digital technologies, participants had mixed feelings. Participant CS3010 states, *"I don't know if I have the motivation or have the time. Being honest."* For Participant CS307, the motivation would come from a competitive advantage and states, *"to keep up, and be able to be on the cutting edge if at all possible."* Participant CS304, however, feels confident in team's ability to learn, and states,

> *We learnt a lot on our own with the digital shifts having not been trained in digital anything. We just picked it up, learnt it, and did it. We're very decisive on what we need and don't need.*

9.9.3 High financial and resource investment

Despite a potential benefit of increased sales and profit margins, management views digital transformation as a high-risk investment. Therefore, Participant CS3011 feels the cost is a significant barrier to taking the initial steps of implementation. Participant CS3011 states,

> *We tried to take steps forward, and I think the biggest thing is we don't know if it will work…if you do make the investment you have to make sure the whole team will use it, and that the customer is going to use it as well.*

Some participants are unsure if the benefits will outweigh the expenses at this moment in time. Participant CS3010 adds, *"Unless someone can actually say this is how much money you're going to save versus the investment."* In addition, identifying the right technology to invest in is unclear. The selected technology would need to add further value than what the product profiles offer. Participant CS301 states,

> *I think the learning curve is identifying the proper horse to ride. If there's three or four different programs out there, what's going to be industry standard? What's going to be adopted by the big players? The cost is definitely a factor early on, but honestly, right now I don't even know what it would cost to do what we need to.*

Participant CS3016 also adds, *"So that's kind of where our hold up has been, which is why the product profiles are just easy."* In addition, there are concerns about who will manage and carry out the digital transformation initiative. Many participants mention that Company 3 lacks internal resources to begin digitising fabrics, nor has the time to train staff to carry out the process. Participant CS309 has found the fabric digitalisation process is *"fairly time intensive"*, based on the quotes from third parties. Participant CS309 states, *"and this was someone whose job it is."* Participant CS306 adds, *"Regardless of how much money we have with those software, we don't have anybody to run them."* Finding a third party to digitise fabrics and create files compatible with 3D design software has been a challenge. Moreover, Participant CS303 is concerned that recruiting and hiring individuals might come *"at a premium"*. In the discussion with Software Vendor CS3, they also agreed finding individuals with the digital skills and product knowledge of denim is difficult.

9.9.4 Intellectual Rights and Privacy

Concerns about privacy issues and intellectual property with information being stored digitally were also mentioned. Participant CS301 asks, *"Will a hacker be able to see all my pictures, my formulas, and my garments? Or to be able to knock off my designs because they hacked into my server?"* When the Company 3 was exploring [Large trade show]'s digital fabric library during the COVID-19 pandemic, issues around intellectual rights and privacy amongst competitors were highlighted. The [Large trade show] began developing their own platform to showcase digitised fabrics. The collections could be viewed with a special login for buyers. However, Participant CS3016 explains,

> *The issue with that was all of the mills were there, and so we felt there was a little bit too much competition. You could see and compare our fabrics very easily. We didn't know if it was secure enough, or if one of the competitors could come into our logged in experience. So, there were just a lot of security risks…*

Company 3 did not pursue the opportunity to showcase within the digital platform. The trade show itself was facing challenges to convince suppliers to buy into their platform. Moreover, some suppliers had already established their own platforms and were unwilling to integrate.

9.9.5 Expectations of technology

As new technologies continue to develop, selecting the right technology can be daunting. Sales and marketing teams compete to showcase the technology's best features by revealing the final output; however, what is not communicated clearly are the required processes, supporting technologies, and hidden costs. Consequently, this might lead to unrealistic expectations and goals, resulting in scepticism about future investment. Some participants found this to be the case while exploring 3D design technology.

In a demo presentation with 3D design software, [Software Vendor A], the presenter demonstrated draping the digital fabric in the program and applying it to a virtual garment. Following the meeting, some participants felt highly frustrated, as they struggled to see how 3D design software is relevant to a denim mill. Despite advancement in visualisation of 3D virtual assets, some participants remained sceptical. This scepticism is possibly due to preconceived notions about the software prior to the meeting. For example, Participant CS304 noted that the fabric in [Software Vendor A], appeared out of focus and low resolution. However, the team did not realise the digital asset was not rendered and would require a separate process and potentially another software. Once the participants realised 3D design software is not a one-size-fits-all solution, they were highly disappointed. It became clear that Company 3 would need to invest in additional skills, training, and internal and external resources. Although many companies are investing in multiple 3D design software solutions, Company 3 is not prepared to make such investments at this stage.

In addition, some participants hoped the 3D design software would allow them to manipulate digital swatches to simulate the wash and laundry process. This capability would allow the team to demonstrate the variety of washes available for each fabric. However, the participants are describing functionalities more akin to generative design or AI technologies, in which 3D design software is not. As software Vendor CS3 explains, *“The tricky thing is that you can't really digitise let's say a raw panel. Then digitally manipulate it so that it's going to naturally look like an actual bleached fabric.”* The properties of denim change as it undergoes a chemical reaction during the wash process. Therefore, it is difficult to simulate the outcomes digitally. Advances in machine learning and data collection would be required to achieve this level of functionality.

9.10 Concerns around virtualising denim product development

Because of Company 3’s reputation and legacy, translating physical to digital while staying true to their craft is daunting. Participant CS3011 states, *“They put their heart, their soul, all of their passion into every product. Those products are their babies.”* Some participants raised concerns regarding virtualising denim product development, including:

- Distrust in the digital twin fabric
- The loss of the tactile element that is crucial to denim development.

9.10.1 Distrust of the digital twin

Some design participants expressed a lack of trust in digitising their products and processes with the current digital technologies available. Participant CS306 states, “*We take into consideration the fabric, the garment, and wash of our materials. Everything has been thought through. How can you transform that into digital?”* Participants question how digital swatches will be manipulated to ensure the virtual swatch is a ‘true’ representation or digital twin to communicate the complexity of denim. Participant CS3011 explains, *“The shade is a really big deal as far as being able to capture that digitally.”* Given the vast number of potential shades in the wash process, Participant CS307 adds, *“You can't really see the depth of wash in photos necessarily. You have to be able to play with it in the light and check it out.”* Additionally, there are concerns about the amount of time required to complete this process.

Despite these concerns, some participants believe that virtualising parts of the product development process could positively impact the design and product development of collections and accelerate the overall process. For example, instead of waiting for physical samples to be shipped from Company 3's mill in Mexico, a digital sample could provide the necessary details and a realistic representation.

9.10.2 Missing the tactile element

Throughout the discussions, a primary concern regarding 3D design technologies is the missing tactile element and the importance of how the material feels, or the 'hand' of the fabric. Especially in regard to denim, Participant CS3011 describes the material as 'extremely unique' with its own particular hand. Because fabric is often a 2D flat surface, the touch and feel element is crucial in the selection process of denim. At trade shows and sales presentations, the first instinct is to feel the material. Participant CS301 explains, *"If it's a tablecloth or a jacket, something that's not touching your skin, it's not as critical. But if it's touching your skin, especially if it's tight fitting, how does it feel? Does it breathe?"* The participant is also concerned that by virtualising the product development process runs the risk of leading to quality errors without physically feeling the fabric. Participant CS301 states, *"Especially early on. Is somebody going to come in and approve a million-yard run without ever touching it? I think there's more of a risk of not meeting expectations."*

The significance of the fabric's hand also varies depending on the target market. For example, the hand of the denim is especially important for women's jeans, as it affects comfort and is often linked to pricing. Participant CS301 explains, *"If you're paying $12 at Walmart, you don't care what it feels like. If you're paying $200, you want to know that it's comfortable."* Company 3's premium brand clients, which often are on a smaller scale, expect the hand of the fabric to be at the highest quality. Participant CS3010 explains, *"Those brands also tend to be more creative, and they tend to push the envelope a little bit more."* The participant also sees a low demand for digital assets from the premium brand clients, as it is more convenient to *"pop down"* to the studio. However, these customers were open to digital solutions during the COVID-19 lockdown. The LA team is open to digital tools and materials and considers them supplementary visual aids during in-person meetings with clients.

9.11 Identifying and selecting digital technologies

Regardless of the chosen technology, both Participant CS304 and CS305 are certain the teams will ensure the technology and its process are not complicated. Participant CS304 explains, *“I would think whatever we do, we're going to make it user-friendly. I don't think we're going to pick anything too tricky.”* When selecting new technologies, participants mention that decision-making will be influenced by several factors, including:

- The start-up and maintenance cost
- Ease of use
- Industry standards and trends
- Clients' current technologies
- Technologies that address the company's present needs
- Features that enhance customer satisfaction and streamline their roles.

9.11.1 Virtual fabric scanning solutions – for the digital library and product profiles

When selecting a virtual fabric scanning solution, participants considered the cost and how accurate and realistic the virtual scan is. Participant CS304 states, *“It has to be realistic, not like makeup…it has to look like our fabric.”* The fabric scanning solutions currently available on the market can be quite costly, with significant expenses for start-up, service, equipment, and annual subscription. From Software Vendor CS3’s research, the initial investment in software and hardware alone can range from USD $65,000 to $80,000.

Although the wash process is carried out manually, there are ways to showcase the variety of washes in high-resolution digital scans to be presented to customers. Multiple washes are required to find the different base shades, typically involving 4 to 7 panels. Software Vendor CS3 has found an industry consensus of 4 panels during the rinse stage (including the enzyme and bleach) to be sufficient to capture the base shades. Therefore, the software vendor recommends scanning the fabric each time it undergoes a wash.

Finishing effects can be applied to digitised images, using rendering software such Adobe Substance or Photoshop on the final garment or fabric swatch. The design team in Hong Kong is exploring a software solution that allows for super high-resolution fabric scans, onto which files of different washes can be applied directly. This would bypass the need for additional rendering. The images are reasonably priced, and the team will investigate this approach further. Since denim is often sold unwashed, finishes such as whiskering are applied after the garment is washed. Finishes like whiskering are often created digitally using laser technology rather than chemical treatments. Participant CS3010 states, *“That's something that translates fairly well on the screen for digital conversation or communication.”*

9.11.2 Selecting a fabric digitiser– for garments in product profiles

As discussed in Section 9.5, the initial digital team explored several technologies relating to digital garment creation – specifically 3D design software. The intended use of these technologies was to support creating a full garment package for a specific client. Alongside the project, Company 3 would develop digital assets to be used internally. Participant CS309 explains the team considered two methods to digitise garments:

Method 1: Take photos of garments in a studio and place the image in a 3D virtual environment.

Method 2: Scan fabric to create digital fabric swatches to be utilised in multiple platforms – such as trailing fabrics in garment form within 3D design software.

Participant CS305 strongly favours Method 1, arguing that 3D design software is more suitable for garment designers to conceptualise market-ready garments. In contrast, Software Vendor CS3 disagrees, believing that digitising the fabric offers greater value as it can be imported into various digital garment blocks. From personal experience, Software Vendor CS3 has found that scanning a final garment is limiting because it ‘locks’ the texture into place. Consequently, any development or minor changes to the garment or textile would require starting over each time.

9.11.3 The debate for 3D Design Software

When discussing digital transformation in regard to the fashion industry, instinctively 3D design software might come to mind. In the context of a denim mill, the application of these virtual tools are questionable. Consistently throughout the visit to Company 3, participants reiterated, *"We are a textile mill. Not a garment manufacturer"*. As discussed in the initial plan to introduce 3D design software in Objective 1, the technology served a clear purpose. However, the debate for the urgency to invest in the technology at the present is divided amongst participants.

No, 3D design software is not a priority.

Some participants feel 3D design software is not relevant to Company 3. Participant CS3012 argues that Company 3 should prioritise investing in a virtual solution that accurately represents the wash and the evolution of washdown shades, as 3D design software may not be suitable for denim. Participant CS3012 states that 3D design software, *"looks cool and fun…but not denim friendly, yet."* The participant believes the technology is better suited for simplistic garments like chinos or polos where *"highs and lows"* in fabric texture are less critical. Once again, some participants express distrust of the digital twin's visualisation. Participant CS305 explains,

> *Our photos really look like an actual garment. Like a tangible physical garment that you could pick up. That's why I'm nervous that these garments look digitised. It looks like it was made in a program. I'm nervous that it doesn't look real.*

If the digital twin could be *more* convincing, the participant would accept the digital model.

Yes, 3D design software is a priority.

Other participants feel 3D design software is beneficial as 3D virtual garments *"tell more of a story"*. Interestingly, these participants argue the current process of capturing the depth of the fabric and flat lays of the physical garments using a digital camera is not sufficient. Participant CS309 explains,

> *These are just flat lays, and it doesn't really have the depth and all the character that denim does have. It's a unique product that*

> *doesn't photograph too well sometimes and has lots of different layers.*

In addition, the 3D virtual garments would allow participants to interact and view different angles of the garment. Participant CS309 states, "*It's more of a presentation like you would have at a trade show."* The participant acknowledges this would not eliminate the need for physical samples, but it would keep the customer engaged. Participant CS309 states, *"I think it would bridge the gap in between until you can really get your hands on it."*

9.12 Plan of action: next steps

In the final meeting to reflect and discuss the next step for Company 3's digital transformation journey, some of the participants within upper management feel there is an immediate need to begin the process. Participant CS303 states, *"We've got the customer side that's driving some of this. There's benefits on the design side, and certainly there's things we could leverage with marketing with the digitised fabric."*

9.12.1 Starting with the fabric virtualisation process

The team feels digitising fabric and building a digital fabric library is the best starting point. The team selected virtual fabric solutions software [Software Vendor CS3]. Participant CS302 states, *"At least for our initial jump into the digitisation pool, so to speak, or dipping our big toe into the digital pool. Let's get on the field, and just navigate how that works for us."* The participants also feel the investment is more 'manageable'. For example, the file format of the scan would be compatible and universal across various virtual technologies. This reduces financial risk and makes the investment more secure while the industry decides which software will become standard. Other reasons to start with digitising fabrics include:

- The process can be carried out with internal capabilities.
- No additional equipment or hardware is needed.
- Meets the current demand for digital fabric swatch files.
- The start-up cost is not a major financial investment.
- Enhances product profiles by replacing 2D flat photos of denim washes with high-resolution digital scans.
- Provides customers 10 different digitised washed fabrics, which is not possible physically.

- Can drive engagement on the company's website and social media platforms.
- Serves as a valuable selling tool at market and sales meetings.

For the time being, the product development assistant will undergo training and manage the scanning process, as the participant already manages the photos for the product profiles. The team will begin with a selection of denim. It is also important to highlight that [Software Vendor CS3] currently focuses only on the 'visualisation' of fabric swatches – not the fabric physics. Software Vendor CS3 explains that the commercial fabric analysers available are similar to those used at the mills for measuring stretch and width. The team concluded that it is worth exploring the possibility of digitising and measuring fabric at the mill level in the future.

9.12.2 Final decision on 3D design software

The participants conclude that 3D design software is not a priority to invest in at the current stage. The cost for a single licence is unjustifiable even though the original budget has accounted for it. If the client asking for full package garments wants Company 3 to have access to the software, Participant CS309 feels the major retailer could possibly spare a licence or consider a third party to create 3D virtual garments. Other reasons to not invest in 3D design software at the initial stage are as following:

- No immediate need as the client in the original plan has paused their initiative.
- There is no one to use and manage the software.
- There is not a high demand amongst all customers at the present moment.

9.12.3 A need for a single product management software

As discussed previously, the importance of the product profiles was emphasised amongst many participants. Although useful, participants feel there should be an alternative solution to automate the process and have a single digital platform to house the information. Currently each profile is created in Adobe Illustrator and kept as individual PDF files, which can be problematic when needed to be updated. Excel sheets are utilised to separate customer accounts, keep up with the styles, and the progress of development. Participant CS3011 would like to find a digital platform with a logged in experience to house the product profiles. The documents contain proprietary information therefore would need to be secured. On the topic of ERP and PLM systems, Participant CS307 feels Company 3 would benefit from a similar solution that is not product specific. However, Company 3 is not ready to begin the transition. Participant CS307 explains, *“We've got a mix of possibly four different systems we use depending on what we're looking for. I don't know if they're all linked or updated manually.”*

The manual process of the product profiles requires the involvement of multiple people and a significant amount of time. In Participant CS304’s opinion, they should be a top priority when exploring digital solutions. Upper management have been discussing this matter, but the budget is the deciding factor. If the team can quantify the time to demonstrate the time savings, Participant CS303 explains it would raise a stronger case to justify the investment.

9.12.4 Future technologies to explore

When discussing mainstream virtual technologies, participants mention artificial intelligence (AI), virtual environments, and QR codes. Some of Company 3's competitors are utilising these technologies. Interestingly, one main sponsor of the largest denim trade show is advocating the use of AI technology to support textile manufacturing operations. While Company 3 is not currently utilising these technologies, the participants are closely monitoring their development for potential future application.

Artificial Intelligence– data driven

In regard to AI, Company 3 is experimenting with Power AI for business strategies, and many participants feel highly positive towards the technology. Participant CS3012 states, *“We can see what's trending and not trending, I think data is king. We live in the world of merchandisers looking at KPI's.”* Data analytics have become an important area of focus. Participant CS3017 explains,

> *We've been trying to make data-driven decisions, and that was something we brought up in the big business meeting last year for this year. If that's where the data is going, I know that this company is probably going to move with it. Having our suppliers join and eventually connecting to the end consumer.*

Virtual environments– Metaverse and NFTs

The topics of the Metaverse, NFT, and digital clothing for videogames are mainstream trends in the industry. Many participants feel sceptical towards these technologies as they are conceptual. Participant CS3012 states, "*Everybody still struggles a little bit to understand the Metaverse and the NFT world, the digital world, the way it's right. It's such a concept."* Although there is uncertainty around what it means for Company 3, Participant CS301 states, *"I think it's coming…While it sounds silly, there's a lot of kids spending a lot of money buying skins for their Fortnite characters, and that's just digital clothing."* The participant predicts that virtual platforms will become mainstream in the next five or six years. However, how it will be monetised and how brands will take advantage of it is not clear. For Company 3, the focus is on leveraging virtual technologies to streamline the sample approval process and enable quicker reactions.

QR Codes– Digital Passports

Some participants see practical applications of QR codes at Company 3 – such as incorporating them on fabric samples to link directly to product profiles. This would allow clients at trade shows to access detailed information on their mobile devices instantly. Participant CS3016 is actively exploring this technology by carrying out conversations with software vendors and industry experts. However, from the design team's perspective, there are concerns that QR codes might not be widely accepted at trade shows. The team noticed the QR Codes provided by the organisers containing information about the trade shows were not utilised.

In addition, Participant CS3012 mentions the topic of 'digital passports' – similar to a nutrition label disclosing the origins of the materials and environmental impact. The participant strongly feels that Company 3 should offer digital passports and include them on all the headers and fabrics. By offering a digital passport, the fabric has an 'identity and a story'. Participant CS3012 believes it can be a tool to educate consumers by raising awareness of what they are purchasing and its environmental impact.

9.14 Final thoughts

Case Study 3 explores a denim mill undergoing digital transformation in response to garment manufacturers and retailers adopting virtual processes and technologies. Consequently, stakeholders, including suppliers along the value chain, are directly affected. The case study highlights the challenge of the initial process of defining digital transformation and objectives as it will differ among organisations. The task of selecting the right technologies to invest in can be overwhelming due to the constant influx of new technologies that often promise more than they deliver. Adding to the complexity is the need to balance Company 3’s specialised product of denim, its various stakeholders, and modernising a130-year-old company.

After spending time at Company 3, one leaves with a greater appreciation for the intricate processes involved in denim creation and production. Denim is truly an art and science, with each step– from raw material procurement to the final garment– demanding a high level of precision and speciality knowledge. The conflict between craft and industrialisation is a prominent theme within Case Study 3. It is evident that the participants take great pride in their craft, and the legacy of Company 3 continues to inspire generations. Therefore, the hesitation and lack of trust of new digital technologies and processes is justifiable.

Although the case study identifies technologies that could assist denim product development, the relevance of certain 3D design technologies remains questionable – particularly for organisations like Company 3. The initial digital transformation plan clearly outlined the incorporation and expected outcomes of 3D design software, driven by a specific customer request. However, Company 3 intends to invest in new digital technologies and processes as a business wide initiative. The case study highlights the need for further research and investigation into the impact of virtualising garment product development, with a focus on suppliers and their responsibilities within this process.

Chapter 10: Findings and discussion

10.0 Introduction to Chapter 10

This chapter presents the findings and discussion obtained from the data collected through three different methods to address the doctoral research question:

> *How is virtualisation of the product development process impacting the fashion industry?*

The study explored the processes by which companies are undertaking virtualisation and the technologies enabling this through empirical research. In addition, issues relating to the fashion design profession, such as craft and authenticity were examined to understand how virtualisation is impacting garment product development. From the data collection, (x18) key findings were identified. Table 10.1 below provides an overview of the main themes, organising the findings to clearly illustrate their relationship with these themes.

Main Themes	Findings
Industry Jargon and Language	• The use and misuse of new industry terms and 'jargon' • Defines key terms that are currently used (and misused) – including digital product creation (DPC) and end-to-end
Digital Pathways	• Two-fold path– digital twins vs visualisation
3D Design Technology Uptake	• Increased uptake of 3D design software as a result of the COVID-19 pandemic • A strong likelihood the uptake of 3D design technology will continue post-pandemic. • Limitations of 2D digital design tools • The impact of 3D design technologies on communication • Fabric digitalisation– the building blocks of virtual garments
Environmental Sustainability	• Can virtualisation support environmental sustainability? • Mapping environmental impact of physical prototypes
Craft and Technology	• The correlation between levels of craft and technology adoption within product segments • Parallels of the Arts and Crafts Movement ideals with Industry 4.0
Role of the Fashion Designer	• Challenging traditional ideals of the fashion designer • The 'Tech Savvy' Fashion Designer

Industry 4.0 and Fashion	• The feasibility of Industry 4.0 for the fashion industry • The social implications of Industry 4.0 in garment production
Support for Industry Change	• Virtualisation as support for industry change • Enabling new business model opportunities through virtualisation • Potential global strategic industry change – reshoring and/or nearshoring
Contradictions and Challenges	• Contradictions and challenges of virtualisation.

Table 10.1 Main Themes and Findings

The following sections will discuss the PhD findings in further detail.

10.1 The use and misuse of new industry terms and 'jargon'

As a result of the COVID-19 pandemic, a systematic shift within the fashion industry produced a new set of terms and industry jargon. With travel bans, lockdowns, and production at a standstill, the pandemic revealed the fragility of fashion supply chains and the industry's infrastructure. Abruptly, the traditional design and product development process came to a halt as brands were unable to receive physical prototypes or carry out physical fittings. Consequently, many fashion organisations turned to 3D design technologies. Terms such as 'digital transformation' and 'end-to-end' became industry jargon, creating urgency to invest in virtual solutions or be left behind. Software vendors, tech start-ups, and consultants rushed to host free webinars covering topics on digital transformation, 3D design software tutorials, and discussion panels on the future of the fashion industry. For marketing and retail, conventional methods and modes of selling also needed to be reconsidered. Virtual fashion shows, virtual showrooms, and gaming became platforms to engage customers because of the travel ban. Trends of the Metaverse, NFTs, video games, digital-only garments entered the fashion market – often referred to as '3D fashion' or 'Digital Fashion'.

In addition, the COVID-19 pandemic heightened the fashion industry's most pressing issues demanding immediate action. The circular economy model and the technologies related to the Industry 4.0 paradigm, such as artificial intelligence, blockchain, etc., were identified and predicted to enable efficiency, offer cost benefits, and support ESG initiatives. Nevertheless, the lack of empirical research and vague explanations of these new terms and theories have generated misunderstanding of the benefits and limitations of digital technologies and virtualisation. As the PhD study began two weeks prior to the UK COVID-19 lockdown in March 2020, these terms have developed and identified areas in which virtualisation impacts.

10.1.1 Digital Product Creation (DPC)

At the start of this PhD study, the term digital transformation was used in regard to the integration of digital technologies within all areas of a business, such as new product or service development, production, marketing, and sales. This might include the use of technologies such as 3D modelling and virtual reality. As discussed in the *Chapter 6 Interview report: findings and discussion,* some participants discussed that the term 'digital transformation' is subjective as it can mean transforming any process or nonspecific industry. When referring to digital transformation or virtualisation, the participants responded by discussing the use and adoption of 3D design software, and the additional processes needed, such as rendering the final virtual garment. The way in which the participants discussed 'process change' is describing the digital product creation (DPC) process. According to Riordan and Yester (2019, p.1), DPC is an end-to-end product lifecycle practice of, "*... designing, prototyping, and verifying products in a virtual and collaborative environment."* Software Vendor Browzwear also defines DPC as the process of *"utilising advanced technology to conceptualise, design, create, and produce 3D products in a virtual, collaborative environment* (Browzwear, 2023)*."*

Most participants in the PhD study were unaware of the term. However, in a personal interview with Participant CMD012, they described DPC as the 'digital umbrella' or digital ecosystem which encompasses 3D design software, rendering software, and the technologies and processes involved in the creation of virtual assets. Participant CMD03 also describes 3D design software as *"an enabler of DPC".* Based on Participant CMD012's research, there are over 20 areas that are comprised of different areas with sub areas. Participant CMD012 states, "*We're probably looking at between 60 and 80 different processes that are supported by multiple technologies that operate across any brand or retailer."* Therefore, 3D design software is not an all-encompassing tool. For example, Participant CMD08 explains that a virtual garment must be rendered to achieve 'realness'. The participant explains, *"It has to be enhanced as it goes through the pipeline from the initial asset to something that's worthy of going on to a website. They think what you create at the beginning is hyperreal enough."* This suggests a reason for the complexity of digital transformation regarding DPC. Each step requires its own procedures, equipment, and research development prior to virtual garment creation. Similar to physical garment production, the quality of materials must be carefully considered when procuring or creating virtual assets, such as the resolution of a digital fabric. As physical garments are made up of a variety of components, other virtual assets, or materials to be considered are:

- Avatar creation of standard fit model.
- Digitising physical patterns.
- Constructing and/or sewing the digital pattern.
- Digitising the fabrics.
- Digitising the trims.
- Rendering the digital garment or asset.
- Animation is optional but requires a separate process.

Regarding a DPC pathway for establishing goals for approaching DPC, Participant CS1010 identified three main types of business models of selling garments, which includes: 1) selling garments digitally 2) storing garments physical or digitally 3) the variety of digital file types. (See Appendix I: Table 10.1 DPC Pathways). Depending on the company's business model, the solutions, workflow, and processes will be different.

Moreover, some participants contend that applying traditional design and development processes in 3D design software is unproductive and fails to utilise the technology to its full potential. As Participant CS1010 explains, *"It should be offering a solution to do what could not be done before."* Companies must balance keeping people motivated, making progress, and building a solid foundation. Instead, brands are focused on how to support files. Participant CS1010 adds, *"They will say they have tried, and it didn't work for them."* The 'failure' of the technology is often the result of several factors:

- Poor change management
- Lack of understanding of what is involved with DPC
- Not having defined goals and outcomes
- Unwillingness to transform processes to support a new way of working
- Building assets with no value– purely visual
- Lack of skills and poor leadership

Furthermore, marketing jargon is likely a key factor contributing to the misunderstanding of the functionality of 3D design software. For instance, the focus is often on showcasing outcomes, such as the final rendered asset and the technology's capabilities rather than the underlying processes. As a result, organisations may find that more resources are required, which have not been accounted for in the initial budget. Many participants shared having encountered this realisation during the initial implementation of 3D design software, and many noted that CEOs and managers only recognise the extent of work involved once the process begins. It was also echoed throughout the data collection that the investment in 3D design software is ongoing, requiring continuous updates in knowledge, skills, and hardware.

In contrast, from Participant CMD015's experience, many brands implementing 3D design software find it challenging, as it is not a fluid or static tool. However, the software was not originally designed for its current use. Participant CMD015 explains,

> *Some of the original documentation from around 2000, there was a project called the Leapfrog Paradigm that Eurotex implemented between 2004 and 2008. A lot of the capabilities that you see in these 3D design software products today were envisioned at that point.*

Originally, the 2D pattern pieces would be draped around the 3D avatar to be stitched together. The 3D software was intended for technical designers with the knowledge and skills to adjust 2D patterns to create 3D virtual models once a design was approved. However, as Participant CMD015 states, *"That's not the way a lot of design works."* At that time, sketching freehand was industry standard as opposed to drawing vectors in software such as Adobe Illustrator.

10.1.2 End- to-end to Support Digital Product Creation (DPC)

Another term associated with digital transformation or DPC mentioned throughout the data collected and industry literature is end-to-end digital transformation. Stapelton and Lindauer (2023) define an end-to-end digital workflow as, *“The processes and tools used to create and maintain an accurate digital representation of your product lines as it comes to life iteratively throughout the go-to-market process.”* Participant CS1010 also defines end-to-end as, *“A platform that enables you to do end-to-end with the 3D digital asset.”* This involves connecting various stages, from initial range planning through to production, the end consumer, and even beyond a product's lifecycle. Therefore, the platform should integrate Excel sheets with range plans and feature digital libraries equipped with navigation options. Users should be able to apply filters and use a search engine to refine their choices. In Participant CS1010's opinion, no one has truly achieved end-to-end digital transformation, and the term remains ambiguous. The practicalities of end-to-end will differ based on the type of business model and what an organisation aims to achieve with DPC. Moreover, connectivity and interoperability are essential to achieve 'end-to-end' in which the industry lacks.

10.2 Two-fold digital path– digital twins vs visualisation

With the hype surrounding virtual trends like NFTs and the increased uptake of 3D design technologies due to the COVID-19 pandemic, the surge of new terminology and technologies can be confusing for industry application. Observations from industry literature and data collection reveal a two-fold path, which are often used interchangeably in industry jargon: 1) digital twin modelling to support back-end operations 2) 'visualisation' for marketing, planning, or 3D art, etc (See Figure 10.1).

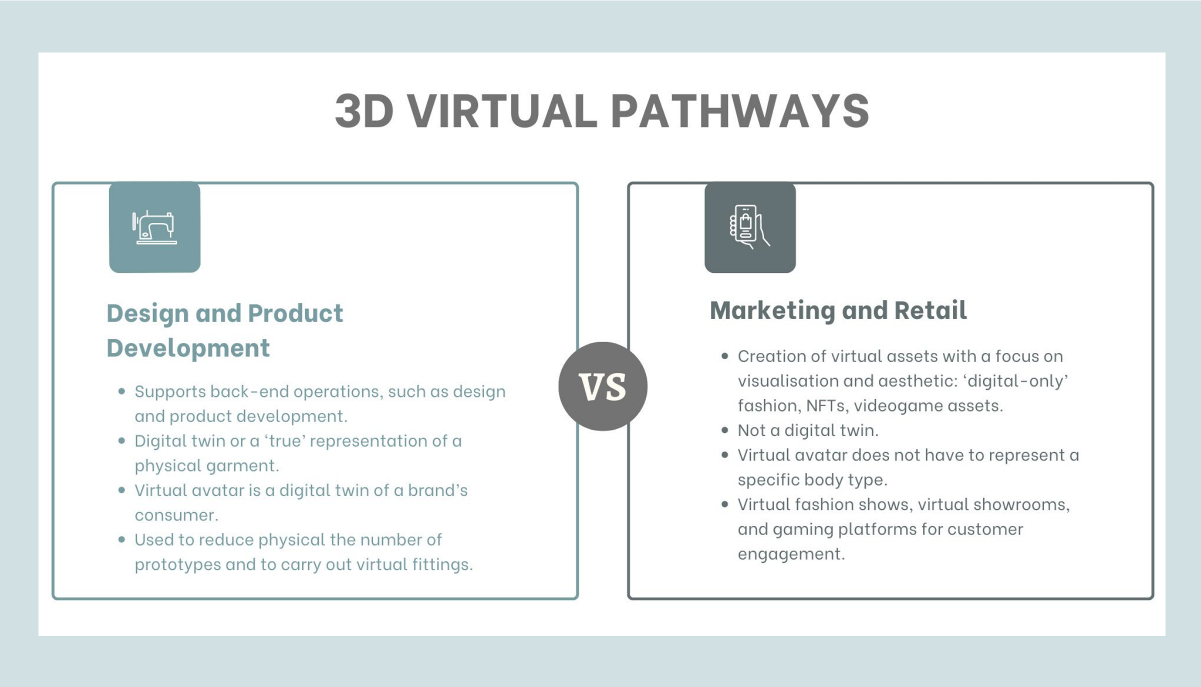


Figure 10.1 Two-fold digital path: digital twins vs visualisation

Determined by the objective of the 3D virtual prototype, the creation processes will vary. For example, Participant DP014 explains,

> *For the marketing part, I'm just creating for the sake of the content. But for the actual virtual prototyping, there are other functions to consider like fit…We can not only share the pretty pictures. So, there are two different perspectives on how these things are being done, and I think both serve an equal purpose for companies.*

This is argued throughout the data responses. For some participants, 3D design technologies support designers 'to expand and create more' through the exploration of virtual mediums without having to physically produce. New virtual platforms such as the Metaverse or 'digital-only' couture houses allow opportunities for self-expression and a new art form. Participant DP04 believes that without the advancement in high-quality visualisation, the industry would not have as much interest in 3D design technologies. The participant states, "*Everyone right now is looking at NFTs, but without 3D [design technology] nobody in terms of fashion would even be thinking about that."*

In regard to practicality, most participants consider creating digital assets for 'visual-only' endeavours a 'waste of time' and resources. These participants argue that virtual assets should be created with the intention to be used end-to-end throughout the value chain where possible. From the survey results, Respondent SR034 states:

> *3D visualisation in the fashion industry is not only about presentation. 3D patternmaking and the 3D design data management are also important. There are too many companies focus[ing] on 3D visualisation and ignore the 3D technology applications in other processes.*

Moreover, many participants emphasise the importance of the physical garment, which cannot be fully replaced with the virtual prototype, as most clothes are to be physically worn. There is concern of turning 'too virtual' in regard to digital-only fashion and NFTs. Interestingly, other participants scrutinise utilising these technologies purely for entertainment as it diverts attention away from major issues in the physical industry. Participant CMD014 states, “*Rather than escape it, let's just fix these first. I find it mind boggling that people think it's just better to live virtually instead.”* This could result in a flawed understanding and approach for implementation, or let alone, a barrier as a result of pre-conceived notions of digital technology as an entertainment ploy not to be taken seriously.

10.3 Increased uptake of 3D design software since COVID–19

Considering either the objective of the visualisation or the digital twin pathway, both processes require 3D design software. From the interview responses, many participants state the COVID-19 pandemic accelerated the use of 3D design technologies for the fashion industry. Participant DP03 states,

> *I think there was a mindset shift globally. I know 3D has been lingering around the fashion industry for a while, but I really think COVID just gave it a big push forward. Most people I’ve spoken to, it seems that COVID was the push that their company needed to say, 'right let's invest in this technology now'.*

As discussed in *CH. 6 Interview results*, the many challenges and barriers in adoption has resulted in the slow uptake of 3D design technologies. In a webinar

(Stapelton and Lindaur, 2023) Stapelton presents Kalypso's survey findings on the uptake and value of DPC technologies in the fashion industry since 2016. The PhD interview results support this study, indicating that the COVID-19 pandemic led to increased adoption of 3D design technologies for DPC (See Figure 10.2). Despite this peak in adoption, 3D design technology has been around prior to. As discussed in the literature review, the virtualisation of garment making systems began in the 1990s (i.e. Hinds and McCartney, 1990) with the practical application of garment simulation. However, the initial application of cloth simulation began in the late eighties and was developed in the area of computer graphics (Volino et.al, 2004).

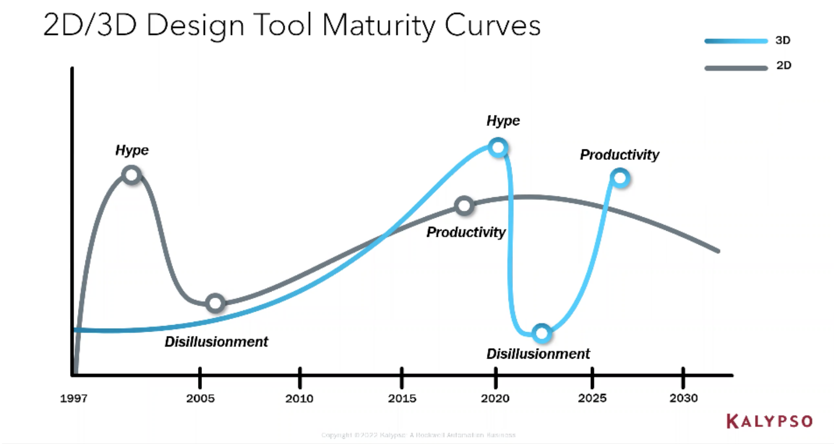


Figure 10.2 2D/3D Design Tool Maturity Curves (©2022 Kalypso) From Stapelton and Lindaeur (2023)

Based on the PhD research, most participants began utilising 3D design software and relevant digital technologies within the last five years due to personal interest or a gradual progression of their role from working with 2D software. Only Participant CMD012 started utilising 3D design technology in 1985, but for a 3D footwear modelling company. In 1999 this participant took part in discussions on developing software for one of the current leading apparel 3D design software. The first practical example from the data collection utilising 3D design technology for apparel/garment product development is in 2011 at a major sports brand for football kits. The technology in 2011 was not as advanced as it currently is, but Participant DP015 explains, "*It was still a really helpful tool to start working with.*" It is noteworthy that the participant was not creating the 3D virtual prototypes but participated in the decision-making process utilising 3D virtual prototypes before committing to the physical garment.

10.4 A strong likelihood the uptake of 3D design technology will continue post-pandemic

As discussed in *CH.6 Interview Results*, some participants are uncertain if companies will continue to invest in the DPC process and the relevant technologies. Participant CMD015 states, "*As far as a catalyst goes, the pandemic definitely forced it. Whether those attitudes will stick around long enough, not sure."* In reference to Figure 10.2, the uptake of 3D design tools peaked in 2020 around the start of the pandemic. However, it fell drastically post COVID-19, alternatively expressed as the *"Trough of Disillusionment"*, as business returned to their offices and factories reopened. The implementation of DPC was not as imperative post COVID-19 (Stapelton and Lindaeur, 2023). However, Stapelton and Lindaeur are observing a heightened sense of urgency and increased interest once more in the DPC process–particularly with regards to the integration of 3D design software and other essential virtual technologies. The suggested reason for the rise in interest is the *"assumed cost of doing business"*. Stapelton and Lindaeur (2023) state,

> *We don't need a quantified ROI to justify some of these programs any longer. The reality is that the qualitative benefits, the need to not fall behind or out of relevance, or completely be behind the industry is a critical enough reason to begin investing in these tools.*

This observation corresponds to the findings from the interview research. For many participants, the reason their companies are undertaking digital transformation is fear of being left behind and to stay competitive as digital transformation is inevitable. In addition, Participant CMD015 predicts operating expenses will be the main driver of digital transformation, particularly in regard to DPC. Participant CMD015 states,

> *If you look at all the revenue that brand makes, about 25% of that covers the cost of goods sold. Whether it's fabric, labour, shipping, tariffs, the margin of their supply chain, or even their own margin…The other 75% is operating expenses, and that can be people, buildings, IT systems.*

For example, it is suggested that organisations invest in a PLM system as part of the DPC framework to manage their process. As organisations incur more expenses undergoing digital transformation, brands may respond by negotiating the costs of garments, fabric, or source from regions with less tariffs. They may also raise garment prices. For this reason, some might argue against the DPC approach. However, Participant CMD015 states,

> *We're so inefficient that if we use this technology correctly then we can maintain our affordable price. Everybody makes money and is happy. We cut out the waste and have a much better product. In manufacturing it's called operational excellence."*

Instead, the participant proposes that an improved design process where 3D design software is utilised to design the garment and to drive processes, such as dyeing and manufacturing, would be more optimal. Participant CMD015 explains, "*Suddenly I've impacted the cost of goods sold, and reduced my operating expenses. That money can go straight to the bottom line or lower the price per garment."* In addition, three elements should be considered: 1) increase throughput to increase the number of products per day with a fixed amount of machinery. 2) reduce expenses 3) reduce inventory as much as possible.

10.5 Limitations of 2D digital design tools

During the personal interviews, participants were asked, "*When did you first begin using 3D design technologies."* Interestingly, this prompted many participants to discuss issues they encountered with traditional 2D CAD software. The four main reasons emerged as follows:

- Traditional 2D design software solutions are challenging to utilise.
- There is a lack of training and industry skill set in digital technologies. Therefore, fashion education needs re-evaluating.
- Cost is a barrier to accessing technology.
- Industry lacks connectivity across the value chain.

This observation is significant, as 3D design technology presents similar challenges and reveals fundamental issues in implementing virtual technologies related to the DPC process. The following sections will discuss these issues in further detail.

10.5.1 Traditional 2D design software solutions are challenging to utilise

Participants mentioned utilising two well-known 2D software for pattern making; however, some participants have found the software to be difficult to utilise and prefer 3D design software. For example, Participant DP015 comments,

> *I can get by with 2D, but when it comes to 3D technology, I find it a lot simpler to use, and a lot quicker to either take a pretty good pattern that's already created and build assets. I wouldn't say I was an expert at all, but I can use the software to look at patterns or build styles.*

In addition, having come across one of the 2D software in search for a virtual technology solution in 2009, Participant DP013 shared, "*We should have used the software, but it was so bad. I couldn't really see how I could use that from a creative point of view."* Similar to others, Participant DP013 found 3D design software more useful. This suggests that the limited adoption of 2D pattern-making software is a result of inadequate usability. Notably, regarding the two 2D software, one acquired the other in 2021.

10.5.2 Lack of training and industry skills — fashion education needs re-evaluating

Many participants brought attention to the need for more investment in training and upskilling in virtual technologies. In regard to digital transformation, the lack of skills in 3D design technologies becomes a barrier for implementation. Participant CMD013 states, "*It's not just buying the technology. It's the skills to use it, and that's an area of a real lack of investment…"* Nevertheless, the underlying problem is suggested to be a limited number of designers with traditional '2D software' skills. Participant CMD013 explains, *"If that pattern expert goes, then another expert comes in. Why not disperse that skill? This software isn't difficult to learn… It's not to say that there aren't highly skilled individuals there."* Often companies will rely on one or a few pattern cutters to utilise the software.

In addition, in reference to the personal interview findings, many participants discussed that 3D design technology and virtual technologies will force designers to understand garment construction instead of relying on the technical team. CMD012 states, *“You've almost got to have an architectural and engineering brain as well as that creative brain. The left and right are coming together.”* Again, participants raise that the issue is a lack of fundamental technical skills, design thinking skills, and a theoretical understanding– *not* a lack of 3D design technology skills. Participant CMD013 states, *“I'm under no illusion we can make tech work, but if your person operating that tech doesn't have the skills and the knowledge, then forget it. It's never going to work.”* This in turn raises a much greater issue and begins to question the effectiveness of the curriculums within higher education– or the power dynamic within social structures.

It could be argued that, given the current industry practices, designers do not crucially need strong technical skills. For example, in high-cost countries, Participant DP05 highlights, “*A lot of the designers don't necessarily have a good pattern background.”* Often fashion design departments are based within head offices situated in high-cost countries, while technical/production teams are found in low-cost countries. Fashion design is highly regarded, as it demands a 'higher intellect' and creative process as opposed to technical skills.

Furthermore, Participant CMD013 states, “*Pattern cutters aren't technically skilled in the knowledge to understand the theory, but they're highly practically skilled.”* The participant notes that while this statement may be perceived as insulting by some, the reality is that there is limited theoretical knowledge grounded in practice. For example, the relationship between the crotch curve of the body to the crotch curve of trousers has no explanation. Participant CMD013 explains,

> *The crotch curve of the body never drove the crotch curve of the trouser, ever. It still doesn't. It could, and it would require an evolution. Skilled pattern cutters are well placed to be able to make that transition in understanding much more than a random unskilled person on an AI computer.*

It is emphasised that the pattern maker still needs to have understanding, knowledge, and control of the garment to construct the pattern despite the technology simplifying the process. Participant CMD013 states, *“I want them to be able to say we put this much ease here, but for this reason. Not the computer decided, but I decided…Let's then get people to engineer fit.”* Participant CMD013 emphasises that while a lack of knowledge is a limitation, it should not diminish the value of practitioners' contributions. Instead, technology should be employed to help designers enhance their skills and ensure they are recognised and valued.

10.5.3 Cost is a barrier to accessing technology

The cost of accessibility is a barrier to the diffusion of digital technologies. This could be attributed to the industry's lack of 2D software skills. Given that software packages can be relatively expensive, Participant CMD013 explains that many independent practitioners will not continue with the software once a trial period is over. However, the high prices are justified by software vendors as their business models are targeted at large organisations. This brings attention to, yet another barrier as financial gain is prioritised over the diffusion of the technology and a wider skills base. Participant CMD013 proposes it would benefit software vendors to offer a smaller fee to encourage a wider user group to use and to experiment with the software to improve its development. However, Participant CMD013 states,

> *But the companies aren't really interested in that...Our biggest problem with digital transformation is the skills to use the tech are in the hands of too few people…Only their workers and those people trained can use it. So, we locked out this kind of the grassroots of the industry.*

This prompts discussion around open-source software in IT and the concept of an 'open-source fashion' system or the 'democratisation' of the design process, which emerged from the data collected as some participants are exploring this concept. However, a key component to drive the development of open-source is a *"secure user community"*. Participant CMD013 states,

> *The very people that need to come on are the people that are hobbyists and learning this stuff in their bedrooms. They can't interact with the technology, and can't use it 'cause the vendors are like, 'well, what's our market share?' …So, across the board with all of this digital tech, it offers huge benefits for being able to drive forward really positive changes. Access is a problem.*

As discussed in the interview findings, many participants feel virtualisation will allow for a democratised fashion system and enable new business models such as the pre-order system. However, this section discussed the barrier of cost in the accessibility of traditional 2D technology, which poses a challenge for the implementation of these new concepts that rely on virtualisation to become feasible.

10.5.4 Industry lacks connectivity across the value chain

Again, in reference to Figure 10.2, Stapelton and Lindeaur (2023) draw attention to 2D digital design tools having increased in maturity and in adoption, but the productivity of 2D digital design tools has not peaked as a result of a lack of connectivity. For example, because 2D digital assets are sporadically shared, Stapelton and Lindeaur (2023) explain, "*Not everybody in the organisation is looking at the most current CAD, and it's easy to get out of sync with one another.*" Connectivity and interoperability have been recurring themes throughout the data collection. The efficiency and full benefits of virtualisation are bottlenecked without connectivity. Stapelton and Lindeaur (2023) states,

> *Our problems are not strictly 3D problems. The vast majority of digital products are still 2D, and brands are struggling tremendously, just making 2D assets available to people so they can make decisions in the right context…You spend a lot of time copying and pasting images, hunting around SharePoint drives, dragging files onto a mirror board.*

Lindaur has found that most brands are storing their digital information in PowerPoint or Excel sheets. The results of the PhD survey supports this as most of the survey respondents are using excel sheets to manage their product development lines. Stapelton and Lindeaur (2023) states, *"There's a proliferation of disconnected products, data, and enterprise…It's hard to decipher, impossible to keep accurate, and tactically. This phenomenon is a huge blocker in the ability to be efficient as a business."* A *"digital thread"* is needed to allow the connectivity of data and digital assets throughout the value chain (Stapelton and Lindauer, 2023). In regard to connectivity, many participants across methodologies discussed the exploration and need for a PLM system as one solution for a more streamlined virtual process throughout the product's lifecycle.

10.6 The impact of 3D design technologies on communication

One notable benefit of 3D design technologies is the significant improvement in communication across teams. The wide range of perspectives from this PhD study is an advantage, as it identifies what teams are affected and how 3D design technologies impact communication. Subsequent sections group cross-functional teams and discuss in further detail the impact on communication.

10.6.1 Fashion Design and Technical Teams

In traditional fashion workflows, collaboration between fashion and technical design teams has often been minimal. However, the introduction of 3D design software has transformed this relationship for some participants by making communication clearer and fostering collaboration. Participant DP09 explains, “*Design was driving everything, and I think it’s really good now that we are working with patterns to create these in 3D.”* This entails both teams meeting and presenting a 3D virtual model before patterns are drafted therefore facilitating a clear understanding of expectations for both parties. At Participant DP05's company, the reduction of physical samples indicates that working in this way has led to improved communication. Once developed, the fashion and technical design teams present the 3D virtual prototypes to managers and merchandising teams.

10.6.2 Managers and Merchandising Team

Some of the participants report communication between designers and merchandisers improved significantly since the uptake of 3D virtual prototypes. Participant DP012 states, *"They can get an actual visual of something before we even start development.”* The 'hanger appeal' or what the garment will look like within its storefront and the product placement is an important aspect of a merchandiser’s role. Participant DP012 suggests 3D virtual prototypes improve communication for those who are more 'business focused'. In addition, if a designer is hand sketching, each designer might have a different style, and there are variations of 2D technical flat drawings. Over time, merchandisers learn to visualise what a garment will look like from a technical flat, but it is difficult to understand what the designer is trying to portray in relation to an overall collection or theme for the season. Participant DP011 states, "*That communication was really strengthened with 3D.*"

10.6.3 Clients and business-to-business (B2B) Selling

Additionally, some participants discussed using 3D virtual prototypes to communicate designs with clients. For example, Participant DP013's company uses 3D virtual prototypes during the planning and design stage with all clients prior to making any physical prototypes. Similarly, at Participant DP04's company, 3D virtual assets are utilised for B2B sales. Traditionally, the company would gather different clients in one room, display the physical prototype, and send photos to the client after the meeting. Now, QR codes linking to a 360-degree view of the virtual product are sent to clients. Participant DP04 states, *"You're getting a whole other aspect of something that you wouldn't necessarily have seen prior to 3D."*

In addition, Participant CMD05 highlights the potential for fabric mills to utilise virtual fabric swatches. Instead of dispatching numerous fabric samples, designers can make initial decisions on virtual swatches in 3D design software. Once the material is selected, the digital file can be forwarded to the garment manufacturer for virtual prototyping and development. This approach facilitates B2B sales and begins to highlight the role of suppliers in a streamlined virtual workflow. The following section will discuss fabric digitisation in more detail.

10.7 Fabric digitalisation– the building blocks of virtual garments

While this PhD study primarily focuses on the apparel/garment sector of the fashion industry, the discussion of fabric digitalisation and its impact on shaping the outcome of virtual garments became an interesting finding. Participant CMD07 states, "*I find the same logic applies as you can't make a high-quality product with poor quality materials. Same thing applies to digital. You can't make a high-quality digital product with poor quality digital materials."* This insight highlights another critical element of DPC that organisations must consider. As discussed in Chapter*. 8 Case Study 2*, fabric digitalisation is a vital and independent process (See Section 8.4.3 Company 2's Fabric Digitalisation Process).

10.7.1 Fabric digitalisation processes

Organisations currently either carry out fabric digitisation in-house or outsource it to third parties, often through their 3D design solutions vendors. However, both options can be time-intensive, as seen in Case Study 2, and require a significant financial commitment. In Case Study 1, fabrics are digitised by a third party in which participants comment on the lengthy turnaround. Therefore, a similar fabric or an estimation of the fabric properties will be utilised. Regardless of the method chosen, a considerable amount of sample fabric is still being exchanged.

Each fabric digitiser vendor uses different analysers and methods for measuring fabric physics along with various scanning solutions for capturing texture, colours, and prints. This raises the need for a standard fabric digitisation process, as highlighted in the case study research. Since measuring fabric physics is often carried out manually, concerns arise regarding their accuracy. For instance, Participant CS204 asks, *“Will it be the same because it depends on the thickness. The weight will be very similar, but are you missing a few millimetres on the side when you cut it? Or how accurate are you?”* The participant found that heavier fabrics curl up when ironed, contrary to expectations. Participant CS204 explains, *“I thought maybe it would straighten it out so it would be nicer for this test, but it actually did the opposite.”* Furthermore, the demeanour of the person carrying out the process can influence the results. Participant CS204 explains, *“So depending on the person's patience, I think that will also change the outcome. You can sit and wait like half an hour for one number then you have a different number.”* The participant shared a notebook with values crossed out, underscoring the variability in measurements. Participant CS204 states,

> *…As you can see here, my patience changed. It’s like that because I thought that now it has settled on a value, but then it would keep moving…I don't know how much the small changes in the value will actually change the fabric here, but it's definitely difficult to make sure that it's 100% accurate.*

Nevertheless, the manual process has provided Participant CS204 with valuable insights into how various fabrics react and how to assess the validity of fabric values. The participant found this learning process to be rewarding.

Some participants, however, feel strongly that the current fabric digitisation process is ineffective. Participant CMD07 argues that for each 3D design software vendor to have their own process is impractical and disagrees that brands should purchase the necessary software and the required hardware. Participant CMD07 states, “*They could have realised that all the equipment is available at the mill. To me this is a bit interesting that they just never even cared to look.”* Since fabric mills test and measure fabric physics to ensure standards on-site, the participant suggests that fabric digitisation should also occur at the mills. This in turn would benefit brands as it would reduce expenses on shipping and sample yardages. Participant CMD07 raises an interesting point that technology vendors and leaders should consider virtualisation starting at the top of the supply chain with mills and work downwards to establish standards, workflows, and integration.

10.7.2 Textile suppliers’ willingness to digitise fabrics

At Company 2, fabrics are digitised in-house, and fabric digitising services are offered to clients. However, the company is a garment manufacturer– not a textile mill. When asking Company 2 participants if their suppliers would be interested in digitising their own fabrics, Participant CS202 states, *“I've talked with a lot of fabric suppliers, and they say, 'We don't care'.”* However, once 3D design software becomes standard industry practice, the participant predicts that large brands will demand their suppliers to digitise. Participant CS202 states,

> *It needs to come from clients like them. They need to force fabric suppliers to do it. To be honest, they [fabric suppliers] already have the information. They just need to translate it into their systems. Because when you do these fabrics, you always do all these measurements we are doing. So, it's just a question of demand from the client.*

Moreover, similar to brands' reluctance to share virtual garment patterns for fear of their competitors copying their product, there is hesitancy to offer digital fabrics open source. Participant CS202 finds this hesitation unnecessary, stating, *“I’ve worked a lot with taking fabrics and designing new fabrics. I can still read whatever you have put in that fabric."* Participant CS201 adds*, “It’s better we give away our patterns. It's better they do good copies than bad.”*

Participant CS202 has observed a growing demand from brands for digital fabrics, as well as other trims and hardware essential for garments. Even YKK, one of the industry's most well-known manufacturing companies, has taken steps to digitise their trims, such as sliders and buttons, and have made them available as open source for designers to use within 3D design software. However, Participant CS202 highlights and states, *“But I think it's easy for them because they always use 3D models or CADS when they produce it. For fabric supply...It's going to go slow.”* Participant CS201 however notes that some fabric suppliers have started to take initial steps towards digitisation, and fabric digitisation is generally slower than for trims.

For both Company 1 and Company 3, the financial investment is too great to digitise their fabrics in-house. While Company 1’s textile suppliers are not opposed to the idea, the cost is not viable. Similarly, Company 3, a textile mill, remains hesitant about the digitisation process. As discussed in Case Study 3, it would require their brands/retailers to demand the service. Participant CS3015 from Company 3 feels it is possible to digitise the fabrics at the manufacturing facilities and the technology is available; however, it is a matter of capital investment. Despite these barriers, the participants are optimistic that the fabric digitalisation process will evolve over time.

Example: Company 1’s internal brand– challenges of fabric digitalisation

The aim of Company 1's internal brand is to create and produce environmentally conscious clothing. Participant CS112 explains, *"Clothes need to be considered in a different way. To see them not as waste, but as a resource to be able to put it back into the Earth."* Natural dyes are developed by utilising leftover natural ingredients such as pomegranate and walnut shells. The brand has carried out extensive research on ethically sourcing and is held accountable by the Global Organic Textile Standard GOTs.

Virtual technologies are also an essential element of the brand to accurately capture data, such as RFID technology, to ensure transparency. 3D design software is also used during the prototyping stage to reduce waste in product development. To carry out fabric digitalisation, the company chose a leading fabric digitising company. However, the brand encountered many challenges such as the following:

- When zooming into the final image, the quality of the scan was poor.
- Since the garments are dyed naturally, there are no Pantone colours, which creates issues when viewing on different devices and monitors.
- Multiple software programs were required to digitise fabrics and render final images, and the team encountered challenges in fixing and rendering the digital swatch.
- Fabric digitisation is still a manual process and is time intensive. Participant CS112 comments, *“I could have done this in photoshop”.*

Participant CS1012 strongly believes that marketing of fabric digitalisation is ahead of the software, and observed the technology is capable of delivering 30% of its claims. Interestingly, this prompted the participant to refer to the level of deception consumers are already accustomed to. For example, the brand's collection included a white t-shirt; however, garments are not naturally 'stark' white. The photographer brightened the image of the white t-shirt as it is common industry practice to do so with white garments. For this reason, Participant CS1012 argues there is discrepancy in what marketing presents and what is promised to consumers. This example prompts further debate of 'what is real' or 'authentic' in fashion.

10.8 Can virtualisation support environmental sustainability?

Throughout the data collection, participants strongly believe that virtualisation and digital transformation is imperative to addressing key issues, especially those related to environmental sustainability. Participant DP03 states, *“I think fashion waste is a massive problem. I think there's some interesting work that could be done using 3D in terms of circularity.”* Virtualisation will be a necessity rather than an option for reducing environmental impact by enabling supply chain transparency and traceability, addressing overproduction, and fostering new business models. Participants highlighted benefits such as eliminating back and forth steps in product development, reducing packaging waste, and lowering freight carbon emissions.

Despite the optimism surrounding virtualisation, many participants highlight that virtualisation alone will *not* solve fashion’s environmental impact. Non-technology-related issues must be prioritised before leveraging virtualisation. Firstly, defining environmental sustainability is essential, as it varies depending on the industry sector. Some participants suggest that the industry should shift from a linear to a circular one business model, while others believe the focus should be on fabric choices or reducing physical prototypes. A standard set of industry terms, guidelines, and framework is needed. Participant CMD015 states,

> *We can't even decide cotton over polyester. One group thinks cotton is great, and polyester is terrible. Another group says polyester is great, and cotton is terrible. You got this term. So, which is it? Once we can focus on these parameters, it'll be easy to deliver on. We have to basically determine what we want first.*

Regardless of whether the fashion industry shifts to a circular business model, the current approach to design would still need significant re-evaluation. Participant CS202 states,

> *We have a lot of clothes today with bad fabrics, bad trims, but with a super high level of production. It's like crossing 2 roads that shouldn't be crossed because it's not durable, not going to last…you have low price productions where you, as a designer, can add so much stuff because it doesn't cost you that much extra.*

Therefore, at Company 2, designs are kept minimal to invest in high-end fabrics and quality production. Participant CS202 states, "*Then you have everything correct, and have garments that last for a longer time instead of the overproduction.*" Company 2 encourages their brands to follow as overproduction is a core issue of the fashion industry's environmental problem. Participant CS202 states,

> *For us, it's still overproduction that is the big elephant in the room. Because it doesn't matter if you do zero-waste, if you overproduce, it's still overproduction. It's still making too much stuff that doesn't sell. Everybody is afraid of selling out.*

10.8.1 Mapping environmental impact of physical samples:

Although a benefit of virtualisation is the reduction of steps and resources in product development, this is often oversimplified. The impact of physical prototypes extends beyond just the garment form to include fabric swatches, which is frequently overlooked. Participant DP04 states, *"There's all these little things that everyday* *consumers or people don't really think about such as the amount of stuff that either is just getting wasted, sold, or can't be sold."*

Having participants from various sectors for this research study offers valuable insights into the use of physical prototypes and samples in textile product development, garment product development, as well as in B2B selling. These perspectives identify practices that could be streamlined through virtualisation. The following sections will outline these insights.

Textile product development– textile mills

While discussions about physical prototypes often focus on garments, fabric sampling in textile mills should not be overlooked. Participant CMD05 states, *"A mill might use 30% of a roll of fabric. It really hit home how much fabric that's never worn. It's just stuff that is made for samples and selling purposes. It just goes to landfills."* Even though sample runs for prototyping garments are smaller, they still consume a considerable amount of raw materials and resources. From a manufacturing perspective, small runs are expensive and inefficient. Participant CMD06 explains, "*It's a big saving for them if they're doing fewer sample runs and more production runs."*

Garment product development – garment manufacturers

Adopting 3D design technology significantly reduces the number of physical samples, which can be a major expense. Participant CMD07 states, "*I've heard from many different parties that manufacturing companies, mostly the fabric mills and garment manufacturers, claim that 25 to 30% of their entire business cost is sample cost."* For context, participants reported creating a minimum of five prototypes per 'unique product' or style – (x3) during the design stage + (x2) during the fit stage. A large brand might produce between 4,000 and 10,000 unique products annually (i.e. 5,000 unique products x 5= 25,000 prototypes). Therefore, eliminating at least one to two prototypes through virtual prototyping has significant environmental impact.

On average, Participant CMD07 has found that one brand will create on average around 120 garment samples before deciding what product will go into the store. In addition, the environmental impact of shipping physical garments back and forth between brand, denim mill, and garment manufacturer must be factored in.

B2B selling – brands and retailers

Physical prototypes are an industry expectation during sales presentations and meetings. A salesperson will often carry them physically in suitcases with various colourway options. However, Participant CMD015 notes that major brands are transitioning to virtual garment samples for the following reasons:

- Producing physical samples is five to ten times more costly per unit.
- The number of sample garments often exceeds the final collection size due to multiple colourways, raising costs.
- After meetings, disposing of sample garments is problematic. While sample sales are offered, these samples are often poor quality. Therefore, these designs in circulation can devalue the brand. Burning samples and dumping them in landfills is also not an ideal solution.

Despite the benefits of virtual garments and fabrics reducing the number of physical samples, buyers at the selling stage show significant resistance.

10.9 Craft levels and technology adoption in product segments.

The literature review examined the discourse between industrialization and craft during the First Industrial Revolution, a dynamic that is similarly evident in the current adoption of 3D design technologies. The PhD research highlights the challenges virtualisation poses to the fashion design profession, particularly concerning craft and authenticity. It also reveals a correlation between market segment and resistance to virtualisation, highlighting stakeholders' attitudes, including those of designers. This raises questions about the relevance of art and craft themes in contemporary industry.

Commercial fashion, which prioritises efficiency and large-scale production, often sacrifices craftsmanship. As Participant DP03 states, *“In terms of commerciality, I think it's really strong. It's a really good easy tool to use in terms of that which is sort of more what we're looking at unfortunately."* Consequently, 3D design technology is viewed as a practical tool for enhancing efficiency in this context. In commercial design, the original design is often compromised to meet budget constraints. Design details like pockets and trims will be removed. Participant CMD015 explains, *“The* *difference between grade and quality grade is the number of features in our product, in quality, and performance to specification."* Nevertheless, the participant suggests that by improving processes through utilising 3D design technology, this could result in higher-grade products at the same cost. Moreover, the personal interviews revealed that 3D design technology fosters creativity and craftsmanship by enabling experimentation and automating mundane tasks. Therefore, this allows commercial designers more time to focus on their creative work.

In regard to luxury fashion, contrasting with commercial design, Participant DP09 considers 3D design technology positive in the way it challenges a designer to find a balance of craft and technology. However, Participant DP09 is more hesitant towards the technology. Because of the brand's high price point, Participant DP09 emphasises that value and quality must be evident to their customer. Therefore, the participant argues that the tactile activities of hand sketching and experimenting with fabric is important to ensure the quality expectation of the brand's consumer.

10.10 Parallels of the Arts and Crafts Movement ideals with Industry 4.0

The Industry 4.0 paradigm shares similar characteristics with the Arts and Crafts Movement, such as consumer involvement in the design process, decentralised manufacturing, and inclusivity through mass customisation. In addition, DPC meets craft criteria found within the literature. For example, learning how to use 3D design technologies requires extensive hours similar to ateliers in haute couture houses. Here, entry-level designers learn from senior designers through hands-on experience to develop precision. 3D design technologies also involve experimentation and have the potential to reshape the relationship between apprentice and master. Participant DP011 states,

> *They can trial and error until they see for themselves what's going to be the best option, but that takes time to trial an error…So having that skill set of that craft will always be invaluable to working in 3D and overseeing to ensure that that process remains efficient.*

As discussed previously, virtual technologies require new processes, which would allow designers to have more time to be experimental. Participant CMD01 states,

> *You can either choose to make it even more sound or go even crazier. I think that's how we should be able to frame technology. Because then the learning is about unlocking new possibilities and not about removing the craft away from your process.*

Individualism is also supported by 3D design technologies. Participant DP012 personally believes that creating in 3D design software can be a craft and allows for self-expression. Participant DP012 states,

> *There's 100 ways to stitch one garment and depending on how you do it and how you stylise it. You add your own touches and your own flare to it. Everyone kind of has their own style, so I think that too can be considered a craft.*

Participant CMD08, however, warns, *"We could almost sleepwalk into that disconnect if we're not careful."* The participant feels the future is exciting, but if not cautious, history of craft can be lost. This aligns with the literature's criteria that craft evolves, but its essence is present.

10.11 Challenging traditional ideals of the fashion designer

When examining the transformative impact of virtualisation on processes, it becomes clear that the traditional designer's identity must shift from romanticism and individualism to a more collective and democratic persona. Discussing 3D design technology and its impact on designers prompted many participants to criticise traditional fashion ideals that obstruct understanding of technology. When asked if virtualisation might raise issues regarding fashion design being traditionally seen as a *craft* or the perceived *authenticity* of products by consumers, Participant CMD013 argues practitioners will have issues with virtualisation – *not* consumers. Many participants mention resistance to 3D design technologies from their design and technical design teams, who prefer to work the *"old fashioned way".* Participant CMD07 states,

> *With [Italian Luxury brand] it was the most hopeless conversation I've ever had. They all walk around with their measuring tapes around their neck. 'This 3D stuff, get out of here. I don't want to hear about any of that.*

Participant DP01 also questions the persistence of legacy designers and courtiers, stating, *“Do they really exist anymore, or is that just a fantasised notion that people won't let die?”* Similarly, Participant CMD02 shared an example from a previous role at a jeans manufacturer, where laser technology replaced hand scraping for finish effects. The denim specialist strongly disliked the laser technology, arguing that a visible difference exists. Participant CMD02 states,

> *I said to him, 'You’re probably 0.01% that could see the difference, but an average consumer can't see a difference'…Sometimes, I think there needs to be a reality check. That level of perfectionism in the industry, is it really necessary? Should we take it so seriously?*

Craft and authenticity is part of a designer’s identity. Therefore, virtualisation can be viewed as a threat if it eliminates the tactile element of sketching, making, and the creative process. Participant DP011 explains, *“If you go into some kind of design field in some capacity you like to do hands-on work. That's artistry at its core level.”* However, some participants argue virtualisation is not demanding practitioners to abandon their creative processes, as many participants mentioned hand sketching remains important and inspiration comes from the physical world. Instead, virtualisation and creativity are two separate processes. For example, Participant CMD02 states, *“I think virtualisation is you put it in a computer instead of starting in a computer, or you enter it later. So, in that sense, no I don't think there's an authenticity issue.”* Virtualisation and design technologies are considered as *"only tools"* or steps in production to understand order of operations. One process is mass manufacturing– the other an artisan approach to production. Participant CMD02 states,

> *I can design it right on the screen. I have the virtual product after the operation in front of me. What production process I use is not a virtualisation topic. That’s where people get mixed up.*

In addition, participants raised the importance of communicating to designers that 3D design technology is not replacing the creative process nor removing them from the process. Participant DP011 states,

> *Look at the technology not as the competition to your modality and your methods. It is a tool in your toolbox…You're still using the same methodology and the philosophy that you might be learning,*

> *capturing, understanding of how that fabric drapes when you change its silhouette…*

Moreover, some participants raised concerns that designers might feel undervalued or reduced to mere "*image producing machines"* if 3D design technology increases expectations from their organisations. Participant CMD08 explains,

> *'Hey, you're working in 3D now, so you can do it that much faster.' There's something about fast being in opposition to craft. Because craft is something considered and takes time, and all those lovely things that we care about in the slow world.*

Many participants stated human involvement is a crucial element in the equation of craft and authenticity. The skilled practitioner can evolve but cannot be removed from the process.

10.12 The 'Tech Savvy' Fashion Designer

When discussing the impact of 3D design technologies on the designer's role and workflow, many participants emphasised the importance of having the 'right' designer. This led to further discussion on the criteria of this designer, described as someone with both technical experience and design thinking skills. Many participants agreed that experience in physical patternmaking and garment construction is essential, especially for design students. Those with technical design backgrounds noted that this experience supported their understanding of virtual garment making. Participant DP03 explains, "*I understand that side of 3D a lot better than some of my colleagues who studied, for instance, textiles."*

Moreover, the data revealed that certain character attributes, such as motivation and curiosity to learn, to be key enablers for supporting and driving digital transformation in the fashion industry. Participant DP011 states,

> *We need to look at digital transformation from the perspective of who in companies and within their roles are actually tech savvy versus not, and what is necessary for those people to succeed on the journey of digital transformation.*

Regarding change management, Participant DP011 argues that it is important to consider more than just employees' feelings and management's clear expectations.

Effective change management involves understanding and acknowledging employees' interest and personal motivations– such as those who are 'tech savvy'. Participant DP011 explains,

> *Tech savviness is an innate skill…Somebody who has an innate ability to learn something and to have an interest in it, of course they're going to excel. They're going to succeed because they understand it. If somebody isn't as interested or they're not as comfortable learning from that tool, they're going to take a lot longer to adopt it.*

Therefore, the willingness or interest to learn new technology must come from the individual. This is evident throughout data collection as most participants expressed having a personal motivation, willingness, or interests to pursue 3D design technologies.

10.12.1 The term 'Superuser' is becoming synonymous with '3D artist'

The term 'superuser' frequently appeared in both the survey data and personal interviews. It also emerged in current job descriptions during the COVID-19 pandemic (See Table 10.2 below). The term superuser is often associated with the computer industry, where it refers to an IT systems administrator. However, this role is not as established in the fashion industry.

Description 1	"Ability to implement best practices for 3D design/tools and complete all trims on digital garments." – Website, 2023
Description 2	"One who understands the needs and is able to streamline the process with her/his 3D technical and apparel knowledge. You will be the go-to person for operational, technical, and training tasks throughout the different projects and seasons: a role that will lead the digital transformation." – Website, 2023

Table 10.2 Superuser role description

Other job titles found include: 3D technician, 3D designer, 3D artist, assistant 3D designer, 3D CAD designer, project manager/team leader of digital creation, associate 3D apparel developer, 3D Technician/ Pattern Maker, Director of digital product creation.

The interview participants provided similar, detailed descriptions of the superuser role. At Participant DP01's company, which specialises in workwear and technical wear, superusers are those with over two years of experience working closely with 3D design software. At Participant DP05's company, a large retailer with multiple concept brands, the role of superuser varies by division. For example, Participant DP09 spends around 40–50% of their time utilising 3D design software but is not involved in company-wide initiatives. In contrast, Participant DP05 utilises 3D design software most days and also plans, leads, and organises 3D virtual design workshops. The participant describes the role as mid-level– meaning it is not upper management responsible for the *"big scope of 3D"* but one level below. Participant DP05 states, *"It's really completely dependent on what they need me for. I'll jump in wherever I can."*

At Participant DP010's company, the roles of 3D artist and fashion designer are distinct and relatively new. Fashion designers carry out traditional tasks such as trend research, range planning, and sketching. In contrast, 3D artists focus entirely on 3D software, creating 3D virtual assets, such as digital materials, avatars, and virtual environments. Within the 3D artist role, there are various sub-roles and specialisations, allowing individuals to choose their career paths or learn a bit of everything. The interview findings indicate a trend towards merging the roles of fashion designer and technical patternmaker. Participant DP010 strongly agrees with this observation, and states,

> *The traditional pattern makers are the major people adopting 3D software. Some of the designers who used to be designers, now they are 3D artists. Some of the pattern technologists who used to work full-time on pattern creation, now are 3D artists.*

Case Study 1 provides additional evidence of these traditional roles merging. The design team no longer waits for the technical team to make edits to a digital pattern within 3D design software. Furthermore, Company 1 has found that fewer fashion designers are needed, while more technical designers are required as a result of adopting 3D design software.

10.13 The feasibility of Industry 4.0 for the fashion industry

Many of the participants view Industry 4.0 as both a general concept and 'buzzword'. While theoretically, Industry 4.0 principles and concepts offer ideal solutions for the industry's pressing issues, establishing a digital foundation is crucial for feasibility. The fashion industry needs defined standards, workflows, and framework for Industry 4.0. Connectivity and interoperability remain significant challenges for implementing 3D design software alone. Participant CMD07 states, *“We're missing that connection between processes. Industry 4.0 was closely related to intuitive things connecting the hardware to the Internet of Things Internet.”* Despite lacking technological connectivity, the fundamental issues of disconnected processes in product development and operating in isolated silos are problematic. For example, brands and retailers typically contact fabric mills for samples and garment manufacturers for prototypes. However, these stakeholders are not seamlessly connected on a single platform and often communicate via email chains. An ideal solution would be a *"super application"* that encompasses all stakeholders throughout the garment's lifecycle. Participant CMD09 states,

> *...Right now, they're doing a lot of individual steps, maybe digitally. But if you have to input a lot of information manually on PLM and have to redo the same thing on another system because they don't talk to each other, that kind of defeats the purpose.*

This would require stakeholders to share information and have a platform that supports various plug-ins to enable automation. Participant DP01 also agrees communication needs to flow between vendor and brand/retailer. However, there is a risk that a competitor brand might undercut and gain the capacity. Participant DP01 states,

> *Once we get them in the game, and we demand that of them, we just made it more competitive for ourselves because now they can take on work from other brands. So just know that dynamic exists as well.*

Once more the theme of relationships, trust, and collaboration is prominent and essential in moving away from traditional industry practice. Participant DP01 suggests, *"How we bring them [suppliers] to the table is we build that relationship in* *a way that we could maybe get an exclusive and protect ourselves in the future."*

10.13.1 Principles of Industry 4.0 and practical shortcomings

Although Industry 4.0 is predicted to create a more efficient and effective manufacturing process for all industries, it should be viewed as a long-term goal once digital transformation and supporting virtual technologies are fully connected and implemented. Many participants in this study were unaware of the Industry 4.0 paradigm or the term itself. Participant CMD02 is the only one whose company, a garment manufacturer, took interest in Industry 4.0 five years prior to the COVID-19 pandemic, using it as a reason to undergo digital transformation. Despite participants stating they are unfamiliar with Industry 4.0, their future visions for their companies align with the paradigm's principles. Additionally, some participants have raised practical shortcomings, as seen in the case study research, which will be discussed in the following sections.

Case Study 1

Although participants in Case Study 1 were unfamiliar with Industry 4.0, the company exhibits characteristics of the paradigm. For example, Company 1 is merging the digital and physical worlds by replacing the traditional product development process with the DPC process. The company utilises 3D design software to create virtual garments that are a true 1-to-1 comparison or digital twin of the physical garments. Additionally, the company actively seeks new high-technologies and strategically plans to ensure connectivity, optimisation, and transparency throughout their value chain. When asked about Company 1's direction, Participant CS1010, mentioned that production is the next area to develop and integrate virtual solutions, such as incorporating IoT technology to automate the collection of key data like CO2 footprint and further optimise product development.

On the topic of Industry 4.0 and smart factories, Participant CS101 predicts it will take considerable time before the industry begins developing smart factories because brands are not focused on made-to-measure business models. Robotics and automating sewing lines in production need further development before implementation. Moreover, establishing well-constructed virtual libraries and ensuring the quality of data are essential. Brands would also need to demand that their suppliers adopt similar processes and relevant technologies to streamline virtual processes and derive benefits.

Case Study 2

The participants in Case Study 2 were also unfamiliar with the Industry 4.0 paradigm despite the fact Company 2 was founded on the idea of an unconventional 'digi-physical' microfactory. The company's product development process was initially carried out in 3D design software, and only production-ready digital twin modelling are developed. However, the production stage is carried out physically with traditional manufacturing technology. Participant CS201 states,

> *Although we've managed to compress the development portion of the brand, everything else is still as it was. The real promise of 3D is to integrate design to manufacturing so that this can be done through algorithms in the program itself.*

Similar to Company 1, Company 2 is exploring how to incorporate virtual technologies within production to enable connectivity and automation where possible. Additionally, the company is experimenting with new business models such as open-source fashion and mass customisation to allow consumers to take part in the design process– another characteristic of Industry 4.0. The company is considering investing in a CNC machine to enable these business models. In addition, Participant CS202 emphasises that technology and virtualisation is *not* to replace workers nor the handcraft if required. Participant CS202 states, *“We don't want to remove the people. It's not what we are talking about…We still want to have the people, but you can automate a lot and digitise.”*

Case Study 3

As a denim mill and supplier, Case study 3 provides a different perspective from the other two case studies. The 130-year-old company continues its legacy as a leader in denim innovation and technology. Company 3 has invested in circular manufacturing processes and partnered with [a technology leader] in cotton traceability– characteristics of Industry 4.0. However, apart from manufacturing, other departments such as design, sales, and marketing remain traditional and outdated. Regarding connectivity, there is a lack of communication through IT technologies between the mills and internal offices. This is evident in the use of four different systems to document the product's lifecycle, as well as the manual gathering of product information and updating product profiles. Participant CS301 explains,

> *Our industry is super old. Our company is super old, and I can't say that we're at the forefront of modernisation of things like this, but our plants have tons of new technologies. We're putting a lot of resources into being at the forefront of a lot of the manufacturing processes and technology there…*

Case Study 3 is an example of how the Industry 4.0 paradigm is context specific. Moreover, the study highlights the impact of garment DPC and a need to redefine roles and responsibilities across the value chain. As discussed in Case Study 3, the creation of denim requires chemical reactions, and cannot currently be simulated to generate desired outcome. However, digital twins of finished garments and swatches demonstrate significant potential benefits for the areas of design, marketing, and sales.

10.13.2 Digital twin modelling in fashion differs from other product industries

Many participants are not currently utilising virtual assets or technologies in production but are carried out utilising traditional manufacturing processes and technologies. As discussed in *Chapter 5 Survey Report: results and discussion*, some respondents feel the industry is not considering other practical uses of virtual technologies, but rather focusing on the *"visualisation"* for marketing and sales. Respondent SR01explains,

> *The concepts of digital twins of the product (3D garment) and production (factory simulation) are only present in marketing material. No one is implementing digitisation in the apparel industry like it is executed in other industries like automotive, aeronautics, and food & beverage.*

From the survey findings, the main area in which 3D virtual prototypes are being utilised is in the Stage 3: Design Development. Despite practical evidence of Industry 4.0 principles, such as virtualisation and modularity in the case study research, the three companies have not yet achieved connectivity from design and product development through to production. For Company 1 and 2, however, the next stage is to explore production and virtualisation.

10.13.3 The physical garment and fabric sample

One of the benefits of virtual modelling is the reduction in physical prototypes. However, some stakeholders might interpret this as *all* physical samples. Participant CS202 states,

> *We don't remove any physical samples. Usually when you do the design and the pattern, if you work in a traditional way, you might have one or two samples that are going to be bad. We remove those. We're still going to have physical samples to test fit, but remove the bad ones.*

In Case Study 2, Participant CS203 explains that 3D virtual prototypes assist in finalising designs, but a physical sample in the intended fabric is still necessary. There are instances when the 3D virtual prototype is limited, and 3D design software cannot account for all situations. For example, when Company 2 supplies a design and tech pack for their client to produce elsewhere, the supplier might have different equipment and use alternative machines, affecting the garment's outcome. Furthermore, Participant CS203 feels most clients are not convinced by the 3D virtual prototype, and shares, *“It feels like they use it as a placeholder until they get the physical sample. It's good enough for now at this stage, but let's make a physical sample to confirm and then we'll alter again.”*

In Case Study 3, participants would consider providing clients with digital swatches as a reminder while they wait for the physical samples. However, as a denim supplier, replacing the physical swatch with a virtual model, for instance at tradeshows, is unthinkable. Participant CS3011 states, *“I would have to say our samples will probably never go away…”* In addition, Participant CS308 states,

> *I think it would have been perceived as almost lazy if a vendor had shown up to a trade show with just a digital showing of their products without actually bringing actual samples. I don't think it would have been perceived very well...*

In *Chapter 9: Case Study 3*, the feasibility of digitised fabric swatches and libraries from a mill's perspective was thoroughly examined. Since fabric is often sold B2B, the tactile and visual aspects are crucial in the buying process– especially for specialised products such as denim. Convincing clients to accept digital fabric presents challenges. Similarly in Case Study 2, Participant CS203 shares this sentiment, stating, *“I was very sceptical about digital fabrics. There's a trust issue with the digital fabric. Is it real?"* The participants have spent a significant amount of time educating and convincing clients, but some clients perceive the lack of ‘realness' as a barrier in decision-making during sales. Interestingly, new start-ups have emerged with a focus on the 'visualisation' rather than focusing on physical properties of fabric.

Moreover, in Case Study 3, the possibility of digitising the final denim fabric is discussed, and virtual solutions tailored for denim product development have been identified. However, extensive amount of research and development are required before these solutions can be used commercially, and before Company 3 is willing to invest. A brand perception survey was carried out by Company 3. (x163) survey respondents, consisting mostly of customers and employees, were asked *Question 2, "Does your organisation have a need or will soon (in the next 12 months) have a need for digital fabric swatches?"* Most of the respondents were uncertain as 46% of participants selected *'Not sure'*, but 31% of respondents selected *'Yes'*. (See Figure 10.3.)

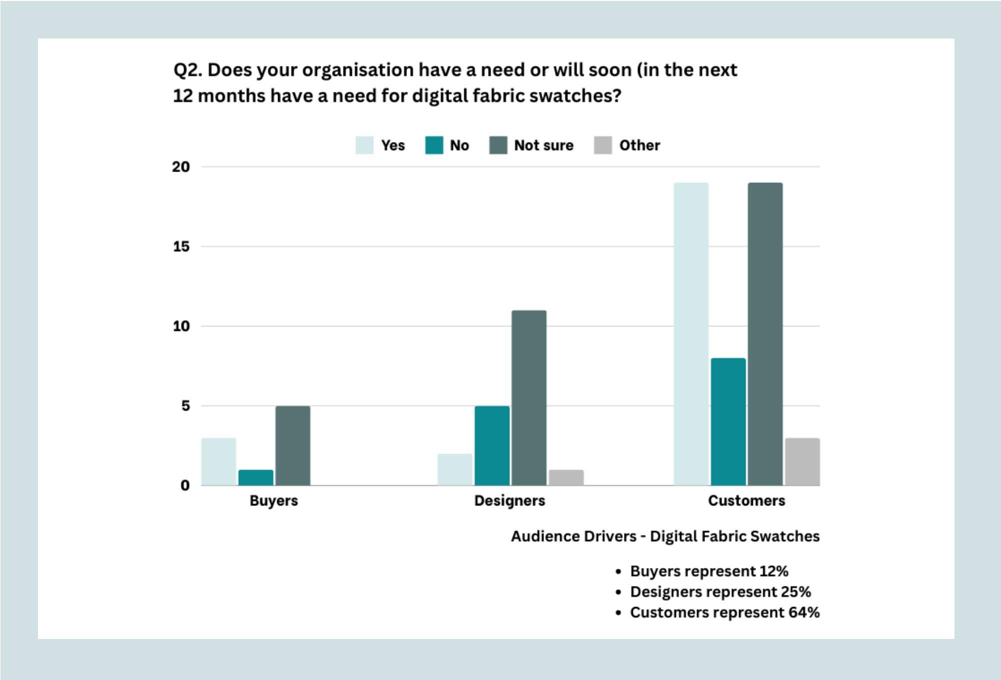


Figure 10.3 Need for digital fabric swatches
Cited from Company 3 Materials (2023), p.24.

Despite most participants from Case Study 3 feeling that garments and fabric samples are essential, Participant CS3011 believes samples could potentially be 100% digital if it becomes more cost-effective. However, while the fashion industry transitions digitally, Company 3 will provide both virtual and physical samples. Participant CS301 explains,

> *There's going to be old school guys that will want the swatch, and they want to feel it and see a garment. Then there's going to be young people just out of school that want to see the 3D and how it looks digitally. So short term, you're going to have to do both for a while until the old folks like me retire.*

10.14 The social implications of Industry 4.0 in garment production

Throughout the data collection, discussions around technology frequently shifted to a more human-centred focus. While Industry 4.0 is predicted to impact 'all' manufacturing sectors, the specific realities of garment production have not been carefully considered. The fashion industry is unique in producing soft goods and has a strong social element tied to its production processes, distinguishing it from other product industries. Connectivity will also be challenging due to the entrenched industry culture of working in silos and complex relationship dynamics.

Garment production involves workers manually assembling garments. Participant CS301 states, *"There's a lot of fairly poor countries where a lot of garments are made… Are they going to have the bandwidth, the technology, and the infrastructure with their internet to be able to do all this stuff?"* This raises questions about who is responsible for educating and investing in technology within these facilities, especially considering many workers lack formal education. Participant CS202 highlights that most factory workers abroad are illiterate, making it crucial to keep assembly instructions simple and straightforward. Participant CS202 explains,

> *They work in pictures – not in text. So, it's also very fun when you meet these different buyers that have never been in a factory. So, they are very well educated, but they don't know how it works in real-life, and they do these complicated tech packs that have never ever been read.*

Both Company 1 and 2 discuss their production teams are located in underdeveloped countries, and they require physical samples to understand the order of operations prior to production. Two physical samples are needed– (x1) at the factory and (x1) sent to the client.

Production, however, can present a positive opportunity for communities in less developed countries. Often companies are incentivised to rent or build factories in the countryside at a lower rate and are required to employ a certain percentage of people around the local area. A school for children is also often mandatory. Participant CS202 states, *"It's been better in the factories, but it can still be better. It's a step in the right direction."*

10.14.1 The textile supplier's role within garment DPC – Case Study 3

Case Study 3 highlights how the impact of brands adopting DPC is gradually extending to their fabric suppliers. One of Company 3's main clients has implemented a business wide DPC plan, raising questions about their expectations and demands of Company 3. This situation calls for a deeper conversation on the roles and responsibilities within DPC. Company 3's initially planned to use 3D design software to develop finished jeans and create digital twins for selection by a major retail client. However, it is important to highlight that this initiative was driven by pressure from this major account holder, rather than being an internal strategy. Participant CS309 states, *“We were getting pushed very, very hard to get completely on board with this by the end of last year.”* See *Chapter 9: Case Study 3 Report* for more details.

The industry's siloed approach skews power dynamics among brands, garment suppliers, and mills, often forcing suppliers to comply. Participant CS308 highlights that each client has unique demands and processes, noting, *“We can set up our own practices and standards, but at the end of the day, when you want that high volume customer, you've got their requests. You've got to bend over backwards.”* Although this digital initiative was paused, the demand will resume, impacting not only Company3, but all of the retailer's suppliers. Participant CS309 reflects on the previous pressure stating,

> *Being a new vendor, we pushed back a little bit saying, 'let's get our feet under us and start moving along a little bit with this before we make this huge investment'. By the end of 2022, they wanted 80 or 85% of all their vendors on board with 3D. So, there's definitely a big push right now for it.*

In a meeting with Software Vendor CS3 about fabric digitisation, one participant questioned whether a textile supplier should subscribe to a 3D design software. This led Software Vendor CS3 to respond with a deep breath, *“These digital tools are not necessarily the lack of technology, but it's more the lack of a workflow in a way that we work together.”* Vendor CS3 implied that the retailer is pushing Company 3, a mill, to become essentially a design house. Vendor CS3 believes that the mill should focus on fabric production and digitisation, while the brand should handle garment design and use the digital fabrics. Software Vendor CS3 states,

> *You're really taking on more of the responsibility of where I think that really the design team and the garment factory would be coming in… Which is again back to that same concept of how maybe brands are trying to shove more work back to the vendors that they work with, and so that they don't have to do it themselves.*

Vendor CS3 proposes a framework for where the mills create and offer a digital swatch library, and designers request sample yardage from the digital library. Consequently, for Company 3, this would reduce the number of headers and legs during the sales process.

This example prompts a discussion around the need to re-evaluate, define, and distribute responsibilities to support and protect all stakeholders across the value chain as new technologies transform the industry.

10.14.2 The garment supplier and brand/retailer relationship

From the survey results, most respondents view their manufacturers' willingness to adopt new technologies positively. However, Respondent 3285 highlights challenges with suppliers, and notes, *"It's hard to train up vendors/factories to meet company virtual standards in a short period. Vendors, factories, and staff are not willing to do business transformation.*" In contrast, Participant CS101 in Case Study 1 also describes the power dynamic between brands and manufacturers, pointing out that brands often prioritise cost over quality. Convincing brands to want more from their manufacturers is challenging because their objective is to simply *"make the product"*. For example, brands frequently send a style to multiple manufacturers, awarding the contract to the one with the lowest bid. Participant CS101 states,

> *If you are always pushing for the lowest possible market, then you don't get the opportunity to invest in new technology or new ways of working. It has been very, very difficult to convince otherwise.*

Manufacturers and producers must prioritise securing budgets and orders, often offering lower rates to brands and retailers who commit eleven months in advance. Waiting until six months before production leads to higher prices, driving suppliers to compete for early orders. Participant CS101 believes that brands and retailers need to shift their mindsets away from solely seeking the lowest price. This issue stems from a lack of broader business understanding, with Participant CS101 stating, *"They cannot calculate by focusing on one piece, and not actually the risk of buying 50,000 in which you only sell 50%, 25%, or whatever…They are sitting in buying and different departments in many companies working in silos."*

10.15 Virtualisation to support industry change

Virtualisation and digital transformation are expected to address key issues in the fashion industry, such as negative environmental impact and outdated processes. The pressure to reduce large amounts of unsold stock is pervasive across the value chain. Participant CMD09 states, *“Every season, they're fighting uphill to make sure they're selling their inventory, and so they're risk averse right now. It's pretty hard.”* Traditionally, design houses would tell consumers what to buy, but Participant CMD015 observes, *“Now people have their own sense of style, for whatever reason, and they're looking for what they want.”* With trends rapidly changing and consumers buying at any moment, the traditional nine-to-eighteen-month lead time is increasingly seen as insufficient.

Brands often struggle with accurately estimating the right amount of inventory. Overestimating leads to excess stock, which is eventually marked down, with additional clearance or liquidation sales not factored into the original pricing. Participant CS1010 notes that approximately 25% of garments go unsold due to overproduction. For example, a company might create 400,000 styles, produce 30,000 styles, and only 3,000 styles will actually be finalised. Conversely, underestimating results in missed sales when demand exceeds supply.

Many participants feel that virtualisation will allow the industry to rebuild or 'revolutionise' the fashion supply chain. Participant CMD010 comments, *“I think if we don't change as an industry, we're further behind than any other industry out there. We're so wasteful and so subjective about our decisions.”* By utilising AI and big data analytics, decisions can be made in real-time and remove guesswork and personal bias. Brands will be more informed in *what* and *how much* to make. Consequently, this will allow brands to make decisions closer to market, and result in fewer markdowns, less leftover stock, and improved customer satisfaction.

In addition, participants discuss many benefits of virtualisation in regard to transparency and traceability. For example, virtualisation provides an easier way to collect and manage product information to enable transparency and traceability–specifically utilising PLM software. By utilising 3D virtual prototypes across the value chain, stakeholders can access product information in real-time. Participant CMD06 states, “*It's much more reliable. For transparency, with digital you have the log of production data about how that fibre, the environmental impact, and the costs. Everything.”* Therefore, decision making is easier amongst stakeholders, and the materials can be traced to their original source. Additionally, Participant DP04 feels using virtualisation to know who is carrying out a task can promote protection of workers. Participant DP014 explains,

> *If you compare working in 3D with someone who is actually going to produce your actual prototype in the traditional way, let’s say in India, then I don't know who is doing it. I cannot trace it. After it’s being shipped, I don't know who opens it now. With 3D I know who opens what. At least I can see the licence.*

In regard to the consumer, Participant CMD07 feels there is a lack of information about a garment's journey when purchasing. As a result, there is no emotional connection with garments. By capturing, validating, and distributing the data, Participant CMD07 suggests this is one way to educate consumers through the use of storytelling.

Some participants, however, believe that transparency is not a matter of technology, but rather a question of ethics and morals. In Case Study 1, transparency is a high priority for Company 1, as a manufacturer. Participant CS105 states, “*Some manufacturers will say it's none of their business, or we just do what we do.”* To ensure transparency, Participant CS104 explains certifications hold the company accountable – not virtualisation or technologies. Participant CS105 explains,

> *You can use any materials in 3D, but if you don’t build up a library of the source materials then there is actually the opposite of transparency. You could say there is transparency if you work in 3D together with the supplier. Then you really have transparency in what pattern is used and what fabric is used.*

Interestingly, Participant DP014 feels transparency will be difficult for companies to achieve because of its 'exclusive' nature. Participant DP014 explains, *“I always know that the fashion industry likes to keep things for themselves. Unfortunately, it's going to take a long time to change this.”* Once more trust and partnerships between vendors will need to be established to allow streamlined product information.

10.16 Enabling new business model opportunities

As more organisations begin to implement virtual technologies and processes, this in turn will drive competitiveness within the market. Participant CMD07 states,

> *All of these independent labels and designers are coming in much more agile and quick. They're adopting these technologies, and really just kind of taken out the market share of T-shirts and hoodies and different product categories.*

Some participants believe that virtual solutions will enable new business models in response to the outdated practices of the current industry. Throughout the data collection, specifically two business models were mentioned based on the current advancement of technology:

1. **Pre-order system** – utilising 3D virtual prototypes to sell designs first to know what to produce and how many units before physical production.
2. **Mass product customisation** – also called 'made-to-order', consumers take part in the design process through customisation of products prior to production.

Both strategies are complementary and can be used together. The following sections will explore each strategy in further detail.

10.16.1 Pre-order system – selling virtually

With the advancement of 3D design technology and high-definition visualisation, many participants discuss the potential of 3D virtual models to enable the pre-order system. Instead of the traditional way of design, make, and sell, designs would be presented with a virtual 3D prototype to gauge interest from consumers. This would allow merchandisers and buyers to place orders based on actual demand, allowing for closer-to-time production rather than making forecasts a year in advance.

Some participants report that organisations are implementing a pre-order system. Regarding the creation of virtual products, Participant CMD012 states, "*If you'd asked me a couple of years back, I would have said no more than 25% of products. Now, I could say some companies are delivering 50% and in excess of 50%.*" Participant CMD09 is also currently working with smaller companies to design products virtually first. These 3D virtual prototypes are then shown to consumer insights groups to gauge interest, potential pricing, and colour preferences. Participant CMD09 states, "*It's going to take a few to really succeed, grow, and be really mainstream. Then I think there will be more adoption."*

Interestingly, some participants point out that other product industries commonly use virtual models to sell products. For example, CMD012 refers to IKEA, where 70%–80% of products are created virtually. CMD012 states,

> *The public will look at them and see real things in their eyes. But they're computer-generated images. This is so powerful to the extent that you could have a kettle digitally created, but it's got steam coming out of it. That's real, isn't it?*

Participant CMD09 also discusses that in product design, for example Apple's iPhone, the product marketing team will conduct focus groups to obtain feedback before creating a product. Participant CMD09 explains,

> *But apparel, we do it backwards. The designer says here's what I want to sell, and then we don't for the most part really get a read on whether that's going to sell until we actually have already produced it. Tens of thousands of pieces, and we find out, 'oh OKAY' people actually agreed with what I had to say'.*

Participant CS203 also supports the idea of using 3D virtual models as a solution to improve product quality and better align production with actual needs. The participant CS203 suggests, *"We can change our behaviour towards buying clothes."* Similarly, Participant CS202 believes this approach could enable closer-to-time production, though it might mean customers will experience longer wait times– similar to purchasing a car or sofa. Nevertheless, Participant CS204 emphasises that educating consumers on the benefits of this model for production and consumption is crucial. Additionally, waiting for a product could increase its perceived value and lead to greater care. Participant CS202 states, *"If you buy something and have to wait for it, you're also going to take care of it because it's going to be special to you."* Furthermore, Participant CS203 proposes remaining stock of basic items like t-shirts and socks. This also means the 3D virtual prototype must be highly accurate to support the pre-order system.

10.16.2 Mass product customisation – 'Made-to-Order'

Virtual technologies such as 3D body scanning technologies and the automation of fit and pattern grading are anticipated to enable mass product customisation. Alongside the pre-order system, mass product customisation is expected to enhance inclusivity by offering a wider range of fit options and democratising the design process. Some participants noted that while consumers desire inclusivity from brands, the industry as a whole has yet to achieve this. Participant CMD01 states,

> *We brag about body positivity. We see all these famous people always wearing particular brands or wearing body positivity fits, but they are not yet available to their customers or for the actual market… it's definitely more sustainable, not just for the planet, but for us to be socially aware.*

By designing for a variety of body shapes, Participant CMD04 feels designers would be designing for *"real women" – not* supermodels. Participant CMD04 explains, *"Because on a model everything looks fine, but when you put it on a woman who is not so tall, then it doesn't look nice."* Virtualisation could enable this reality.

10.16.3 Microfactories

Topics of on-demand manufacturing and reshoring/nearshoring are also discussed in regard to the pre-order system and mass customisation. For this to occur, a digital supply chain becomes even more crucial to support small batch runs of mass customised products. Furthermore, many participants highlight the paradigm shift of reshoring or nearshoring to reduce environmental impact, overcome supply chain challenges, and support new business models. For example, in Case Study 3, regarding denim, Participant CS3012 observes that organisations are increasingly carrying out certain garment processes locally rather than abroad. Participant CS3012 explains,

> *A lot of stuff is happening in the US. A manufacturer in LA has automated cut and sew to around 80%. They have machines for the pockets and spreading lines of the fabric. They even have lasers. There's automation. You can do that stuff in Pakistan or Bangladesh. It takes 1000 people. Here, you can do it with 50.*

Microfactories, which support decentralised production, are also a component of Industry 4.0 and the circular economy framework, enabling local or nearshore manufacturing. For example, Participant CS202 states, *“Let’s say you are in South Africa. Then we would produce it there because that makes sense. So, you keep it close to production.”* Company 2 has attracted several high-end clients within Europe because of their manufacturing capabilities as a microfactory. One client, a major technical wear brand, approached Company 2 due to their limited space and lack of in-house designers at their head office in Germany. In addition, developing complicated and technical products with their factories in Asia presents challenges such as long lead times in product development and language barriers. External factors, such as the COVID-19 pandemic, also demonstrated the risks of outsourcing abroad.

There are, however, barriers to this model. As discussed in Case Study 2, manufacturing in high-cost countries will be expensive, and a lack of skilled workers is also problematic. Participant CS202 states, *“…. Right now, we are two people short in the factory, but in one month as it looks now is enough. It would be helpful if we could have a second factory in Finland, or wherever.”* Interestingly, Company 2 envisions having multiple microfactories across various regions, highlighting a circular economy mindset of sharing resources. In this instance, it would involve redistributing skills to meet high production demand in certain areas.

10.16.4 Open-source garment manufacturing

Both microfactories support the open-source fashion framework complement each other in supporting decentralisation and localisation of the fashion industry. According to Mustonen (2013, p.12), open-source fashion has the potential to enable, *“localisation and decentralisation processes of the fashion industry.”* As discussed in Case Study 2, open-source patterns would allow consumers to alter and submit production-ready patterns to be sent to the CNC machine. Participant CS202 explains. “*Then if we need to produce it, you don't have to cut it yourself, but only sew it together.”* Rather than brands design products based on their target audience, Participant DP011 states,

> *This has an impact on the type of products that we're making for them that impacts the overall process. If we are to virtualise that, it opens up that in a way what you create digitally. It is accessible no matter where you land on the income field.*

This would enable collaboration with consumers during the design process. Similar to how digitisation has reshaped the relationship in consumption of music, print, and photography, Participant DP013 predicts the fashion industry will undergo a similar transformation if 3D design software becomes open source. Participant DP013 states, *"Long-term I'm sure that this will also change how we relate to fashion and might shape how we're related to trends, vanity, and dressing. It might change the concept of a dress."*

For this model to succeed, virtual assets libraries would need to be available as open source. Brands would need to provide access openly. While many virtual assets are being created, they are not available to the public. Participant CS202 states,

> *The problem is still when we talk to [large commercial brand] who have their own library of all the fabrics they are using in their world. Anyone inside can see it, but coming from the outside, I can't see their library. It's also stupid keeping things hidden.*

Therefore, the team challenges brands to consider opening their libraries to the public. Moreover, Participant CS202 questions the necessity of secrecy in the fashion industry, and states,

> *If you ask a brand, 'this button, where did you buy this?' They don't tell you. I can remove one and send it to my button supplier. They have the same one...So I think that this is also a hurdle we need to cross over to get everybody to understand that it's not rocket science we are doing.*

The ability to customise products and consumers wanting to express their individuality raises questions about the relevance of brands. Participant CS202 states, *"We're going to see a moment move away from [brands], and it scares a lot of the fashion brands now."* Participant CS202 explains that in Sweden, the cultural norm is to look like everyone, *"It's like a copy paste on every person you see in the city."* Participant CS202 states,

> *Denmark has passed us so long ago because the individual person is more valued if you look a bit different. Here, it's how dare you be your own person, and I think that's going to change a lot...And when you can do your own garment, you're going to see a big difference.*

10.17 Potential global strategic industry change – Reshoring/Nearshoring

The fashion supply chain faces numerous challenges, including economic crisis, environmental concerns, and political factors. In addition, the COVID-19 pandemic exposed its fragility. However, in Case Study 1, Company 1's strategy to move production closer to Denmark across multiple locations proved successful in navigating the pandemic's challenges. Participant CS101 states,

> *None of these places were closed down at the same time, so we could move orders from one place to another. So, it was a combination of luck that we have the same fabric and good planning.*

Compared to the manufacturers who carry out production in one country or region, Company 1 was able to reduce the number of delays. Instead of producing full orders, Company 1 maintained a steady replenishment for their customers. Participant CS101 states,

> *That has been an eye opener that maybe it's not a good idea to put all your eggs in the same basket, but to have a supplier who has a certain flexibility in where they're doing their production. When you can send in the order and have the garments in your house in less than two weeks. That's a very short time.*

Similar to Company 1, Company 3 has found having multiple production locations is a competitive advantage as it enables flexibility and agility. Company 3 has two facilities in Mexico and one in China. Participant CS306 states, *"Out of all of our industry competitors, they can't say that they're not stuck in one country."* Participant CS306 also highlights that demand fluctuates. For example, Company 3's China facility has seen a decrease in demand, but the demand is higher in the Mexico facilities. Participant CS306 states, *"But we see it happen all the time. Mexico is huge and then it goes to China. Then to Indonesia and to the Middle East. Then it comes back to Mexico. It's always shifting."*

With some brands seeking to move production closer to market, the paradigm shift of offshoring production in the 1990's is slowly returning in response to contemporary issues facing the fashion industry. For example, Participant CS101 found the price to produce in Europe was more or less the same in comparison to the escalated freight prices. In Case Study 3, Participant CS301 states,

> *In 2019, we were paying around four grand for a container from China. It got up to around USD $26,000 last year for a 40-foot container. So, it's outrageous! Now it has come down a little bit, but it's still USD $12,000, and that's why a lot of people are nearshoring.*

If stakeholders throughout the value chain worked together to reduce resources, cut costs, and create optimal processes, Participant CS101 believes the fashion industry can overcome the rising costs of cotton and distribution to maintain low consumer prices. Participant CS101 states,

> *You can increase the price a little bit, but the competition is so hard. You're probably not able to increase the prices as much as you would like because you will probably lose market shares. So, I think a lot of brands will be forced to look into the way they're working and see where they can make some changes.*

Having production closer to the source provides many benefits such as shorter delivery times, traceability of products, and reduces environmental impact. In addition, smaller garment runs are a key benefit. Participant CS101 explains, *"Instead of buying 50,000 units, maybe start with 2,000 or 3,000 to find out if this is a good seller or not. If it is, then buy 5,000 more. You can have it two weeks after."* For example, at Company 3, Participant CS306 explains many clients will buy the same fabric which will need to undergo six different washes. If the fabrics are made in Asia, the decision has to be made at least 12 weeks out. Participant CS306 states, *"Here, what sold last week, they've got all the garments made. OKAY, throw them into this, and they're making decisions a lot closer to the market. So, less closeouts, less rebates, less lost sales due to empty shelves."*

With brands and retailers looking for ways to cut lead times, produce closer to time, and overall shorten the fashion calendar, this will create a strain on their suppliers, such as Company 3 who will have to run and store smaller lot sizes. Participant

CS306 states,

> *Instead of them buying 500,000 yards of this, they say I'm going to buy 10–1000. Then I want 10,000 more, and then I want 10. Or what didn't sell? I'm going to switch…So we've seen our lot sizes drop considerably over the last several years…*

Company 3 is capable of carrying out smaller dye runs; however, denim requires several runs to keep the dye consistent. For example, out of a 7,000-yard run of denim, Participant CS306 explains that the first five hundred and the last thousand yards are of no use. A continuous run of fabric is required to achieve high quality denim. In addition, Participant CS306 states, *“There are boutique mills out there that do 500 yards, but that's probably hand dipped. That’s very expensive."* Due to smaller runs requiring more setup time and the amount of waste generated, manufacturing costs will increase. However, Company 3 is seeing a higher demand for smaller runs as clients are making decisions closer to time. Clients would send orders six months prior. Now orders are made a month at a time.

10.18 Contradictions and challenges of virtualisation

Virtualisation has the potential to support industry transformation, create new business opportunities, and offer a wide range of benefits. When discussing these benefits, some participants also raised contradicting responses. For example, customisation might allow consumers to connect emotionally with their garments, and in turn create a desire to keep them longer. However, Participant CS1011 argues it could have the opposite effect where an automated process results in no emotional value. In addition, generative design may result in further overproduction of poorly designed garments and exploitation of workers. Participant CS201 states, “*I think the challenge here is to try to do good things from it and creative things.”* This section will explore four main contractions from the data collection.

10.18.1 Further negative environmental impact

Interestingly, some participants raise the issue that the pre-order system and mass customisation may result in further negative effects on the environment. For example, 3D design software might result in reducing the number of physical samples and waste during the prototyping stage; however, it could have the opposite effect by enabling even more production. Participant CS203 states,

> *I'm not really expecting 3D to help combat this problem in the current model because it doesn't help us much. Maybe they can make designing easier, and they produce more as production time is shorter, right? Would that mean that they can have five seasons in a year or 12 seasons. I don't want it to be like that.*

Participant DP01 also raises the same concern but hopes fast fashion companies would use it to only produce what is demanded. Participant DP01 states, "*It defeats the purpose of their model, but it would be really fantastic if we could get to that place where we're only making what the demand requires."* Similarly, Participant CMD04 feels this could result in *"unintentionally driving people to buy more stuff".* Participant CMD04 explains,

> *Although we might be having less iterations of any particular style to create it, anything that makes people think, 'hey, ohh I can customise that and buy it for next week'. Then that's going to push people's buying habits in the wrong direction, and then what do we do with those garments?*

In addition, Participant CS1010 highlights that only producing what is needed has in fact been achieved with fast fashion. Participant CS1010 discusses the 80/20 rule in fast fashion where 80 percent of profit comes from the 20%. Fast fashion companies keep costs low by reducing the product stock by shortening the fashion calendar to produce only what is needed. From the literature review, this is describing the just-in time manufacturing strategy. As discussed in Section 10.9, the fashion segment that is more likely to adopt high technologies will most likely be in lower fashion segments, such as fast fashion.

10.18.2 Hindering designers and furthering exclusivity

When discussing 3D design technology, most designers felt highly positive, and mentioned many benefits in support of the designer. However, Participant DP014 feels digital tools might cause young designers to over create, which could result in unrealistic expectations, burn out, and mental health issues. The participant feels digital designers are creating an excess of virtual designs and selling them cheaply. Participant DP014 states,

> *To me that's kind of the same thing as fast fashion. You're creating for the sake of creating. You're not creating for the sake of a bigger purpose…I don't want designers to jump on this digital trend thinking I'm gonna be the next big 3D designer because it's not like that…Then they'll say it didn't work out.*

In regard to topics of Web 3.0 and virtual assets, such as NFTs, to democratise and decentralise the creation process, one might argue they are in fact more exclusive. Participant DP03 states, *"I think very high-end designers are getting behind and selling their NFT. And I think this might be a slightly less accessible part or virtualisation."*

10.18.3 Ownership of intellectual property and policy making

Some participants raise concerns that virtualisation will create issues around ownership and confidentiality. For example, brands might outsource their designs to a 3D artist to create a 3D digital garment. When a design is approved, a vendor such as the garment factory will purchase the materials, manufacture the garment, and ship them on time. In this case, who owns the digital asset? Participant CMD015 states, *"Unless the brand has put something in their contract with the vendors about who owns the patterns, then that can be a problem."* However, often the pattern that the brand or retailer receives from the factory, is not the same pattern used in production– which accounts for the fabric yield. Fabric yield is how the shape of the pieces are laid out to utilise as much of the fabric as possible to avoid waste. Participant CMD015 states, *"It's not unusual for garment factories even after a garment is approved to change things so that they're not losing money."*

More the concern around the social impact and legal protection of stakeholders as technology develops quickly was raised. Participant DP011 states, *"Everyone is so distracted with the boulder of digital transformation standing in front of them. I worry that policy is going to be lacking for some time, and that will cause a lot of issues."*

10.18.4 Virtual selling needs further development

In regard to virtualisation allowing brands and retailers to offer more products closer to market, Participant CM010 feels there is a risk in overwhelming customers with products, and states, "*I think we're already pretty overwhelmed."* The participant believes there is great potential to increase the customer experience through the pre-order system and receiving direct customer feedback before production. However, Participant CM010 explains, "*I've seen some of that happen before, but I just don't think it's necessarily being executed as well as it could have been.*"

After discussing the 'sell before you make' strategy with several large brands using 3D virtual models, Participant CS203 found that consumers generally react negatively to virtual models. On the other hand, Participant CS204 notes that customers make purchase decisions based on photoshopped visualisations of garments on models. The participant finds it intriguing that while people connect with rendered photos of real models, they struggle to relate to avatars in the same way. Participant CS204 concludes,

> *I guess because you're used to seeing a picture that is also edited, but now you see another version of a visualisation of the clothes. So, I think that it doesn't translate as well as when you see an avatar instead of a real person in a garment.*

Both Participants CS203 and CS204 found there is a disconnect with customers and digital selling with one project in particular. Company 2 along with [an experimental brand] specialising in NFTs, experimented with the concept of creating digital for the physical world. A Swiss military M70 Jacket was re-designed in 3D design software to create the NFT and for production-ready patterns. Once a certain amount of NFTs were sold, the buyer had the option to trade in the NFT jacket for a physical jacket in which Company 2 would produce. When the NFT jacket launched online, sales were slow. However, once it was modelled physically there was a higher level of buying activity from consumers. Participant CS203 states, *"There is still a disconnect. People cannot really understand the feel of the garment."* Furthermore, Participant CS203 has seen interest from clients to create promotional materials such as animation videos of the 3D virtual garments. However, these clients tend to be smaller companies and more willing to experiment. Interestingly, none of their regular clients have used the digital files to sell directly on ecommerce sites or are interested in NFTs and the Metaverse. The demand is still for physical products or 2D patterns to be sent to suppliers. Similar to Company 2, when asking Company 1 about the 3D digital file and prototype, their clients are not interested in the files after production or for their ecommerce sites and marketing.

In regard to virtual fit, Participant CS201 suggests more development is needed before wide commercial adoption. The participant has tried a virtual fitting application, and found it to be 'decent'. Participant CS201 states*, “It's kind of not sexy enough yet for consumers I think.”* The participant feels when brands have their garments digitised, this will allow for consumers to be able to visualise the garment better in 3D before purchasing. Participant CS201 states, *“Then we can talk about the digi–physical objects and [open-source platforms].”*

10.19 Summary of findings

This chapter presents the findings and discussion addressing the doctoral research question: *How is virtualisation of the product development process impacting the fashion industry?* The study explored how companies are undertaking virtualisation and the enabling technologies through empirical research. It also examined issues related to craft and authenticity within the fashion design profession, focusing on the discourse between craft and technology, and the acceptance or rejection of virtual technologies.

The data collection revealed significant patterns, trends, and implications, highlighting the intricate dynamics and feasibility of virtualisation in garment product development. The researcher identified (x18) key findings from the data. This section summarises the main highlights and takeaways from the comprehensive investigation.

10.19.1 The evolution of the PhD study

The COVID-19 pandemic exposed the instability of the fashion supply chain, forcing brands to seek alternative solutions as factories and global offices closed. This systematic shift led to the emergence of industry terms and jargon. Terms such as 'digital transformation' and 'end-to-end' became mainstream industry topics creating urgency to invest in virtual solutions or be left behind. Many design and product development teams turned to 3D design software to carry out garment prototyping and digital fittings. Virtual fashion shows and showrooms emerged as key strategies for presentation and marketing. In addition, brands began engaging with consumers through videogames and the Metaverse. Terms such as '3D fashion', 'Digital

Fashion', and 'Digital-only fashion' suddenly became trending and emerged in marketing jargon.

Prior to the COVID-19 pandemic, both academic and industry literature lacked empirical research and clear understanding of terms in regard to virtualisation and digital transformation. This gap itself is a significant finding of the PhD research. Since the study began two weeks before the UK COVID-19 lockdown, the meanings of these terms have evolved. Two terms from the data were particularly significant in understanding how companies are undertaking virtualisation and implementing the technologies: 1) Digital Product Creation (DPC) 2) End-to-end digital transformation.

In this study, the term 'digital transformation' refers to the integration of digital technologies within all areas of a business. Participants often discussed the subjectivity of this term or referred to the use of 3D design software to create virtual garments. In addition, DPC emerged as a significant term, encompassing 3D design software, and identifying other supporting technologies and processes in the creation of virtual garments. Participant CMD012 described it as a 'digital umbrella'. The way in which participants discussed 'process change' within the context of digital transformation aligns with DPC.

Furthermore, to support DPC, the term 'end-to-end' was frequently used in discussions of digital transformation. Participants often referred to end-to-end in the context of using a virtual prototype from 'concept to consumer', or in marketing jargon as virtualising the supply chain. However, the term remains loosely defined as both ideas lack clarity regarding which areas of supply chain and which teams are included. The industry is not as high-tech as perceived, resulting in a disconnect between current capabilities and anticipated outcomes. Though context-specific, the common thread is the connectivity of processes and tools needed to support the virtual asset throughout the value chain. Consequently, many participants believe that true end-to-end integration has yet to be achieved. A major reason for this is the fashion industry's lack of IT infrastructure to support connectivity and interoperability.

10.19.2 How companies are undertaking virtualisation

A two-fold path became evident in the debate for the application of virtual garments: 1) digital twin modelling to support back-end operations 2) 'visualisation' for marketing, planning, or 3D art, etc. The chosen path determines the processes and the required technologies. Arguably, all the participants in this study agreed path 1) digital twin modelling is the correct approach to gain the most benefits. Physical samples are still crucial for ensuring quality in product development and production However, virtualisation can reduce the initial samples.

The COVID-19 pandemic led most of the participant's companies to uptake 3D design software. Despite the uncertainty of some participants, there is a strong likelihood that this adoption will continue post-pandemic. Interview findings indicate that participants are undertaking digital transformation in regard to the DPC process for reasons such as fear of being left behind, to stay competitive, to drive optimal processes, and meet business requirements.

While discussing the benefits of 3D design technology, this prompted many participants to discuss the challenges of 2D design software, such as the ease of use. These challenges of traditional 2D design software are significant as there are similar challenges with 3D design software. However, participants raised three fundamental challenges not inherently a 2D or 3D problem:

- Lack of training and industry skill set in digital technologies.
- Cost is a barrier to accessing technology.
- Industry lacks connectivity across the value chain.

Additionally, participants highlighted many benefits of 3D design technologies, with improved communication in the product development process and selling stage. Three main groups were highlighted:

- Fashion Design and Technical Teams
- Managers and Merchandising Teams
- Clients and B2B Sales Teams

The findings clearly show the impact of 3D design technologies on teams.

10.19.3 Fabric digitalisation

The primary focus for this PhD is the apparel/garment sector. However, this study raised the importance of fabric digitisation within the DPC process and the outcome of the final virtual garment. This insight highlights another area within DPC that organisations must consider. Additionally, this finding underscores the need to re-evaluate the roles and responsibilities of stakeholders as more companies begin digitally transforming. While this PhD study highlighted the involvement of a textile supplier in the DPC process, it also reveals that attention must extend beyond just brands and retailers.

10.19.4 Craft and authenticity

Craft and authenticity emerged as significant themes in this PhD study, highlighting the discourse between craft and technology influences the acceptance or rejection of virtual enabling technologies. The findings, supported by academic literature, reveal a correlation between the level of commercial readiness and the adoption of virtual technologies. Companies that are more commercially focused are generally more willing to invest in virtual technologies.

Resistance to technology in the fashion industry can be found throughout history. Parallels of the Arts and Crafts Movement ideals can be drawn with the contemporary paradigm shift of Industry 4.0 discussed in this chapter. This finding is significant as it reveals the discomfort of fear associated with new technologies, while also offering insights and understanding to overcoming these challenges. In addition, the discussion on virtualisation and 3D design software highlighted the challenges these technologies pose to the role of fashion designers. It further highlighted themes of craft and authenticity concerning a designer's identity. The ‘Tech Savvy’ Fashion Designer emerged as an interesting discussion, reflecting the evolving skill set required for future fashion designers.

10.19.5 The feasibility of Industry 4.0

The Industry 4.0 paradigm has become a popular discussion within the academic literature across various industries. Despite its potential to modernise outdated practices, the feasibility within the fashion industry remains uncertain. Barriers such as a lack of a technological foundation and siloed operations hinder connectivity and interoperability, as repeatedly discussed throughout the data collection. In addition, Industry 4.0 is a *manufacturing* paradigm rather than a design and creative one. While virtualisation, including 3D design software and virtual prototyping, is often discussed in relation to Industry 4.0, its impact on garment manufacturing and production is yet to be considered. The case study research revealed practical shortcomings in production across all three companies. The data collection confirms that digital twin modelling is not fully integrated into the supply chain. It typically concludes with the technical team, leaving the production team reliant on physical samples. This highlights the need to consider the stakeholders in the production sector and the challenges they may face in adopting new virtual technologies. Despite evidence of Industry 4.0 principles, such as virtualisation and modularity, full integration into garment production has yet to be achieved.

10.19.6 Virtualisation to support industry change

The COVID-19 pandemic heightened the fashion industry's most pressing issues. Literature highlights paradigm shifts towards a circular economy and Industry 4.0 as key to support ESG initiatives to drive industry change, with both relying heavily on technology and virtualisation. While technology theoretically supports these paradigms, participants identified fundamental, non-technological challenges in addressing the industry's environmental impact. These challenges include defining environmental sustainability and establishing stand processes. Participants also suggested shifting from a linear to a circular business model and carefully considering material choices. While discussions often highlight the reduction of physical garment prototypes as a benefit of 3D design technology, the diverse sectors represented by the PhD participants offered practical examples of the environmental impact of physical samples from textiles mills to the B2B stage. Consequently, it identifies where virtualisation has the ability to reduce waste across the value chain. Moreover, some participants anticipate the emergence of new business models enabled by virtualisation to address issues such as overproduction. Two frequently discussed models based on current technological advancements, are:

1. **Pre-order system** – utilising 3D virtual prototype to sell designs before physical production begins, allowing brands to gauge demand and determine what to produce.
2. **Mass product customisation** – also known as 'made-to-order', this model involves consumers in the design process by allowing them to customise

products before they are produced.

The discussion of these business models promoted participants to highlight themes of on-demand manufacturing and reshoring or nearshoring. This underscores the importance of a digital supply chain in supporting small batch runs of mass-customised products. In addition, many participants believe that these approaches will reduce environmental impact, address supply chain challenges, and support new business opportunities. Both business models align with the 'open-source fashion' paradigm, which aims to decentralise fashion manufacturing and production through microfactories. Microfactories are an element of the Industry 4.0 paradigm, promoting decentralised production and supporting a circular economy framework by producing locally. However, challenges such as shortage of skilled labour and the high costs of manufacturing in certain regions pose significant barriers to this approach.

10.19.7 Contradictions and challenges of virtualisation

Despite the positive attitudes towards virtualisation and its potential to drive positive change in the fashion industry, some contradictions emerged in the responses. For example, while the pre-order system and mass customisation are seen as advancements, they may inadvertently lead to increased production and further environmental impact. Additionally, while some design participants acknowledge the benefits of virtual technologies such as 3D design software, there are concerns that virtualisation might create unrealistic expectations from management, potentially leading them to over-create.

In closing, this chapter presented the PhD findings on the impact of virtualisation on the fashion product development process. While implementing virtual technologies offers significant benefits and opportunities to transform the fashion industry positively, numerous technological and social challenges remain. Traditional notions of fashion craft and authenticity are challenged. Nevertheless, stakeholders must embrace new innovation and industry change to stay competitive and meet consumer demands. Collaboration and adaptability are essential to fully realise the potential of virtualisation and advance the industry for the common good.

Chapter 11: Conclusion

11.0 Introduction to Chapter 11

In conclusion, this chapter presents an overview of the PhD research project. The doctoral research addresses the question:

> *How is virtualisation of the product development process impacting the fashion industry?*

The focus of this research investigates the apparel/garment sector of the fashion industry, specifically examining design and product development. Additionally, this led to touch upon aspects of production.

To thoroughly investigate these areas, an interpretivist approach was adopted, utilising ethnography as the primary research method. To address the research question, this study undertook empirical research, using both quantitative and qualitative methods. The three methods used for this study includes (x1) survey, (x35) interviews, and (x3) case studies to answer the project objectives as follows:

- To understand the processes by which companies are undertaking virtualisation and the technologies enabling this.
- To understand the impact of virtualisation of the product development process on the fashion industry.

    – including how virtualisation of design and product development processes has impacted issues relating to the fashion design profession, such as 'craft' and 'authenticity'.

This chapter is divided into four main sections, providing a concise summary of the key findings and discussion, contribution knowledge, limitations, and further research of this PhD study. The chapter begins with exploring the main findings and discussion, highlighting key insights and their implications.

11.1 Findings and Discussion

The doctoral research identified (x18) key findings. However, this section reviews six significant findings and discusses their contribution to knowledge. These findings include:

- Lack of empirical research on virtualisation in industry practice
- Evolution of industry jargon and conceptual frameworks for virtualisation
- Essential technological ecosystem for enabling virtualisation
- Practical applications and challenges of virtualisation in companies
- Practical realities of the Industry 4.0 paradigm
- Discourse between craft, authenticity, and technology

These findings represent the most crucial insights from the research, providing valuable contributions to the understanding of virtualisation in the fashion industry. The following subsections explore each finding in more detail, examining their implications and significance.

11.1.1 Lack of empirical research on virtualisation in industry practice

The initial themes investigated in the academic literature included: virtualisation, 3D design technology, digital transformation, and Industry 4.0. However, the literature was scarce and dispersed across a broad range of disciplines. For example, studies on 3D design technologies within the fashion industry are found in fields such as computer science (e.g., Zhang et al., 2008), textile science and engineering (e.g., Papahristou and Bilalis, 2017), and marketing and management (e.g., Conlon, 2019). Additionally, developed areas of research focus on individual technologies such 3D printing and 3D body scanning technology.

Regarding virtualisation within product development, literature on the feasibility and effectiveness of streamlining design and product development remains limited. Main pieces of literature include Paparhistou (2016) and the LEAPFROG project– Leadership for European Apparel Production From Research along Original Guidelines (as discussed in Freund, 2008). However, since the COVID-19, these themes have gained significant interest in academia and industry. For example, Weinswig et al. (2022) conducted a qualitative study exploring the challenges and benefits of 3D design software and DPC. Similar studies include Casciani et al. (2022), Särmäkari (2021), and Sayem et al. (2022). In industry literature, virtualisation has also attracted attention, as evidenced by reports from Kalypso (Riordan and Yester, 2019) and Just Style (Barrie, 2015).

The PhD study builds upon key pieces of literature, such as Papahristou and Bilalis (2017), Alfaro and Arribas (2018), and Bertola and Teunissen (2018). However, these foundational studies require further comprehensive analysis, as they are confined to a single methodology and lack in-depth empirical research (See Table 11.1). Appendix A also provides a full list and summary of relevant literature prior to the COVID-19 pandemic.

Main pieces of academic literature
Study and date: Papahristou, E & Bilalis, N. (2017) **Title:** 3D virtual prototyping traces new avenues for fashion design and prototyping development: a qualitative study." **Research focus:** Analyses the current state of 3D virtual software solutions and the adoption and implementation of early adopters for 3D prototyping considering barriers, challenges, and opportunities. **Method(s) used:** Interview research (unstructured) **Industry of focus:** Fashion **Department:** Within the school of production, engineering, and management **Country of focus:** Global industry – 12 countries in total **Document type: Journal Article** **Note:** Available before 2020
Study and date: Alfaro and Arribas, (2016). **Title:** Digital transformation of a small fashion house: a PLM implementation **Research focus:** To explore digital transformation, key roles of information technologies, and Product Lifecycle Management (PLM) software in the fashion industry. Key themes: Digital transformation, technology implementation, product lifecycle management. **Method(s) used:** Inductive Case Study **Industry of focus:** Fashion industry– Haute Couture **Country of focus:** France **Document type:** Journal Article

Note: Available before 2020
Study and date: Bertola and Teunissen (2018). **Title:** Fashion 4.0. Innovating fashion industry through digital transformation. **Research focus:** Projecting exploring the potential impact of Digital transformation to lead to Industry 4.0 for the fashion industry. **Method(s) used:** Literature and Research Paper **Industry of focus:** Fashion Industry **Country of focus:** General Manufacturing Sector **Document type:** Research paper **Note:** Available before 2020

Table 11.1 Main pieces of literature

There are many shortcomings within the academic literature. For example, there is a disconnect and contradiction between the theoretical claims and the actual uptake of 3D design software in the fashion industry. Prior to COVID-19, some studies suggested that 3D virtual prototyping was being widely adopted as a result of technological development (e.g., Hegde, 2018; Hwang and Hahn, 2017). However, these studies lack empirical research, and the PhD findings indicate otherwise. While there has been an increased interest in 3D design software within DPC, it has not yet become standard practice in design, product development, and production. Casciani and Wang (2022) also suggest that 3D design technologies are not widely adopted and remain in the conceptual phase (Sun and Valtas, 2016) or ‘exploratory’ phase (Arribas and Alfaro, 2018). Many companies have only recently begun adopting 3D design technologies in response to the COVID-19 Pandemic. Moreover, the existing literature and the PhD findings have highlighted significant challenges and barriers, which have contributed to the slow diffusion of digital technologies, as noted by Papahristou and Bilalis (2017).

Currently, the academic literature regarding virtualisation and digital technologies is often generalised or exaggerated in marketing jargon. This leads to misunderstanding about the technology and its role in various processes. For example, Arribas and Alfaro (2016) investigate the use of PLM software to digitally transform a fashion brand from ‘concept to consumer’. The study also used other digital technologies, such as 3D design software. Despite selecting a brand specialising in couture garments, the case study experimented with footwear. The study does not take into consideration that the fashion industry consists of various sectors and product categories. Therefore, clothing and footwear will require different software and processes.

Many studies focus on the creation of hard fashion goods in relation to these technologies, such as footwear (e.g. Arribas and Alfaro, 2016), jewellery and notions (e.g. Pasricha and Greeninger, 2018; Yap and Yeong, 2014), or avant-garde designs seen on the runway (e.g. Cabigiosu, 2020). Furthermore, 'concept to consumer' requires connectivity to production and suppliers, which the academic literature often does not consider. These research studies are theoretical and conducted in controlled environments. Similarly, these issues are present in studies regarding specific 3D design technologies or discussions on mainstream paradigms, such as Industry 4.0 and digital transformation. For example, researchers examining 3D printing technology– also known as additive manufacturing or digital fabrication technologies (Casciani and Wang, 2022)– have identified many limitations regarding its use at scale in manufacturing of cut-and-sew garments. The technology remains largely conceptual (Sun and Valtas, 2016).

Similarly, although 3D body scanning has appeared in the literature since the 1970's, the industry also continues to struggle with establishing standardised applications (Gills, 2016). Consequently, practical applications on a larger scale are not yet feasible. Supporting this, none of the PhD participants are utilising 3D printing, and only a few are exploring 3D body scanning for product development. Therefore, with a more accurate and clearer understanding of the fashion industry's technological landscape, researchers and industry professionals can begin to develop practical solutions and measurable outcomes.

11.1.2 Evolution of industry jargon and conceptual frameworks

At the beginning of the PhD study, buzzwords like 'digital transformation' and 'Industry 4.0' were often used interchangeably to describe the adoption of 3D design and virtual technologies, particularly in response to the COVID-19 pandemic. The term digital transformation in the fashion industry remains ambiguous due to the complex and interconnected nature of the fashion supply chain, which involves suppliers, manufacturers, and brands/retailers. However, over the duration of this study, new industry jargon, such as digital product creation (DPC), emerged, leading to more precise terminology. This finding provides a clearer understanding of how companies are implementing virtualisation and the related technologies, helping to contextualise and identify specific processes. By compartmentalising these systems, researchers and industry experts gain a comprehensive view of the feasibility of positive paradigm shifts, such as Industry 4.0 or a circular economy.

The current academic research often describes the adoption and use of 3D design software to create virtual garments as digital transformation. However, what academics and the PhD participants are describing is the DPC process. DPC is a more accurate term, as it describes the overarching umbrella or digital ecosystem encompassing multiple technologies and processes for the creation of virtual assets.

The term DPC can be found as early as 2004 in the automotive industry (as seen in Depince et al., 2004; Vaidya, 2019). In the fashion industry, the term DPC is mentioned in Lurie's (2016) study on sportswear brand Nike's advanced manufacturing processes. However, the study focuses on trainers or sneakers rather than soft goods such as garments. The application of DPC, in regard to 3D garment virtual prototyping, in which the PhD participants are undertaking, is also found in the literature, starting from 2016 (Paparhistou,2016). Various terms for DPC related to digital transformation include Digital Product Development (Senayaka, 2015), 3D virtual prototyping (Papahristou and Bilalis, 2017), and Virtual Product Development for creating digital twins (Riedelsheimer, et al., 2020).

The inconsistent use of terminology complicates discussions about specific 3D design technologies and their role within the value chain and poses challenges in locating relevant academic literature. By creating standard terminology, a common language can enhance understanding of the technologies. In turn, this enables informed decisions and strategic implementation that benefits stakeholders across the value chain. Adopting digital product creation (DPC) as a standard term in both industry and academic literature can contextualise the integration of these technologies these technologies can be integrated for more responsible, efficient, and effective industry practices.

11.1.3 Essential technological ecosystem for enabling virtualisation

Building on the previous section, implementing a technological ecosystem that integrates a range of technologies and processes is essential. However, the garment lifecycle is not linear and involves many stakeholders, making it challenging to identify the steps and technologies needed in the product development process. Moreover, the industry is made up of various business models and product levels, resulting in varied workflows that add to the complexity. Participant CMD012, a pioneer in DPC, noted that there are currently over 20 areas with sub areas requiring between 60 and 80 different processes. Failing to understand that 3D design software is only *one* tool within the DPC ecosystem hinders the implementation and future development of a virtual ecosystem.

The literature identifies technologies such as PLM software, 3D design software, and Industry 4.0 technologies as enabling virtualisation (see Table 2.2 Industry 4.0 Technologies in *Chapter 2, Literature Review*). However, the PhD study highlighted the limited current use of these technologies (see Table 6.2 Types of 3D design technology in *Chapter 6 Interview report: findings and discussion*). Some of the participants continue to search for a compatible PLM software, while the majority rely on Microsoft Excel as their main product management tool.

Most participants began using 3D design software and rendering tools due to COVID-19. However, to date, there is still not an established standard software. In the interview responses, three main 3D design software solutions were mentioned, with some participants using multiple software to support different clients. Some participants described their organisation as 'tech agnostic'– indicating a belief that no single technology solution is sufficient.

In addition to 3D design software and other virtual technologies, such as radio frequency identification (RFID) and blockchain, are predicted to support environmental, social, and governance (ESG) initiatives (Imed, et al., 2021, Chen, 2023) by enabling traceability and transparency in the fashion industry. Digital technologies are considered critical in this equation by collecting and facilitating accurate data (Imed, et al., 2022). Many of the PhD participants also believe that virtual technologies have the potential to address key issues facing the fashion industry, while others see virtualisation as a partial solution to these issues. The fundamental issues participants feel virtualisation might address are:

- Supporting environmental sustainability – (most discussed)
- Supporting social issues: diversity, inclusivity, and democratisation of fashion
- Restructuring the fashion supply chain
- Enabling transparency and traceability

Post COVID-19, these challenges have become even more pressing as EU legislation and government policies are taking action to hold organisations responsible for their environmental impact (Abdulla, 2022; European Commission, 2023). The European Commission is set to mandate digital product passports across industries by 2024 to ensure traceability and transparency (Damen et al., 2023).

Regarding social issues, the fashion industry has faced significant criticism for promoting unrealistic body and beauty standards, leading to various social challenges (MacCullum and Widdow, 2016; Amed, 2013). Consequently, there is increasing pressure on brands to adopt more inclusive practices. This study highlights the potential of virtualisation to support a more inclusive and democratic fashion industry. According to the data collected, participants identified two key approaches to achieving this: 1) offering a wider size range of garments and 2) implementing mass customisation with digital twin avatars. For these approaches to be applied on a larger scale, the discussion of an open-source fashion system is essential. Additionally, the concept of an open-source fashion emerged as a prominent theme in Case Study 2, providing practical evidence of organisations exploring a decentralisation of the product development process to involve customers more directly.

11.1.4 Practical applications and challenges of virtualisation in companies

The COVID-19 pandemic profoundly disrupted the fashion industry by accelerating digital transformation and sparking interest in related virtual technologies for wider adoption (Nafz, 2022). Most PhD participants noted that the COVID-19 pandemic was indeed the catalyst for their companies to consider DPC. With global lockdowns and travel bans, brands and suppliers rushed to find alternative ways to interact with customers, moving away from traditional methods such as physical fashion shows, showrooms, and sales presentations. Brands began experimenting with virtual solutions like utilising CGI models and environments, as exemplified by Burberry (Tsai, 2020). Virtual platforms, video games, virtual fashion shows, and NFTs became new forms of expression and presentation to engage consumers (Milner, 2021). Meanwhile, the fashion supply chain came to a standstill, prompting many brands to invest in or prioritise the implementation of 3D design technology (Socha, 2020). From the data collected, there are two digital pathways organisations are undertaking in the use of 3D virtual prototypes and assets:

1. Digital twin modelling to support back-end operations
2. 'Visualisation' or high-quality renders for marketing, planning, 3D art, etc.

This is an important finding for addressing the research objectives because the chosen path will determine the process, purpose, and the required technology. Throughout the study, most participants expressed scepticism about using 3D virtual assets solely for marketing, citing a lack of further functionality. For example, a digital twin model allows the original pattern block to be reused for new seasons. Nevertheless, organisations are not fully leveraging digital twin capabilities as other product industries do, from design to the shop floor. The current workflow of 3D design software is criticised by participants for being counterproductive, as it still follows the traditional processes of design and development.

In addition, practical challenges arise in the adoption and implementation of virtualisation, such as the initial start-up time and cost, upskilling designers, and IT issues like hardware and interoperability of files. Management teams will often overlook these variables. Despite the challenges, participants highlighted numerous benefits, as evidenced by practical examples from the case study research:

- **Case study 1**: This study demonstrates how 3D design technology enhances agility and efficiency for a traditional garment manufacturer. The benefits exceeded the company’s expectations, prompting further exploration of virtualisation opportunities.
- **Case study 2**: This case involves an organisation founded on digital principles in response to the inefficiencies in traditional design development

and production. Virtual technologies enabled practical exploration of themes relating to this study, such as Industry 4.0, democratisation of the design process, mass customisation, and decentralisation of production.

- **Case Study 3**: This study reveals that the adoption of 3D design software by brands and retailers is directly impacting textile mills and suppliers. Insights from Company 3, a textile mill, highlight how the demand for digitised fabric affects sales and presentation, and underscore the power imbalance between brands and their suppliers. Moreover, it explores the practicalities of how suppliers, such as Company 3, can begin to transition to virtual practices.

Furthermore, participants expressed concerns that virtualisation could lead to additional negative outcomes, such as further environmental impact, job loss, and an overwhelming amount of product options for consumers. Nevertheless, virtual technologies such as 3D design software continue to prove beneficial post COVID-19. This study found that the benefits– such as time and cost savings, along with improved efficiency and communication among cross-functional teams– outweigh the disadvantages. The same benefits are echoed within the academic literature, as seen in the LEAPFROG project.

According to Imed et al. (2022), investing in virtual technologies remains a priority for organisations due to rising labour, transport, and raw material costs. The PhD research also indicates operating expenses and market competitiveness will eventually drive the need for virtualisation within product development. However, operating expenses of high technologies will need to be strategically considered.

11.1.5 The reality of Industry 4.0 for the fashion industry

The Fourth Industrial Revolution or Industry 4.0 has gained much attention amongst academics and is anticipated to transform traditional industries into sophisticated virtual ones (Duarte, et al., 2018; Ganji et al., 2018; Morrar, et al., 2017). Unlike the past three industrial revolutions, the Fourth Industrial Revolution is the first to be examined prior to occurring (Hermann, et al., 2015). Therefore, the paradigm is "*highly unexplored"* (Bertola and Teunissen, 2018, p.352), and the term is not yet clearly defined (Hermann, et al., 2015; Fettermann, 2018). Industry 4.0 encompasses a range of virtual technologies, each requiring separate studies within various contexts, such as blockchain (Viriyasitavat, et al., 2018) or IoT (Ghoreishi and Pynnönen, 2020). Despite its goal to transform production and manufacturing, (Ganji, et al., 2018), the practical application of Industry 4.0 in the fashion industry remains questionable.

The six principles of Industry 4.0– such as interoperability, virtualisation, decentralisation, etc – are problematic in relation to the fashion industry. For example, Rudolf et al. (2019) discuss the use of wireless networks to transmit 2D/3D digital patterns to cutting rooms. Unlike other industries, the apparel/garment design and production are not often connected (Freund, 2008). Specifically, the application of 3D design software in garment production for Industry 4.0 appears impractical based on the case study research conducted. Therefore, while the concept of end-to-end digital transformation and connected systems throughout a garment's lifecycle is appealing (Nafz, 2022), the reality is that garment production is often carried out manually in low-developed countries. As highlighted in Case Study 1, many workers in these regions have little to no IT experience.

During the data collection, only a few participants cited Industry 4.0 initiatives as the primary reason for undergoing digital transformation and adopting DPC. However, there is evidence of organisations supporting Industry 4.0 themes, as demonstrated in Case studies 1 and 2. Throughout the research, themes such as mass customisation and decentralised manufacturing were frequently discussed in the context of digital transformation, 3D design software, and virtualisation. All participants expressed optimism that implementing DPC could lead to the development of new sustainable business models – i.e. mass customisation and pre-order systems. While Industry 4.0 concepts like smart factories and co-creation are often associated with DPC, the actual implications and feasibility of these paradigms require further exploration. The academic literature has overlooked the social impact of these technologies in apparel/garment production.

The politicisation of the language of Industry 4.0, has currency / kudos, but it is not the reality of where the industry is. The PhD study has uncovered social elements involved in apparel/garment production and raises the concerns of the viability of virtual technologies within production. This highlights a crucial need for general and fashion education to consider stakeholders along the whole value chain.

11.1.6 Discourse between craft, authenticity, and technology

Exploring themes of craft and authenticity became important in the context of this PhD study. Both terms emerged while reviewing industry literature and during data collection. Despite their ambiguous and subjective nature, two main areas where the themes intersect with the study include:

1) **The discord between virtualisation and craft preservation:** Virtualisation can be perceived as challenging traditional craft values. This tension presents itself in two ways:
   - **Designer's identity:** Some designers are concerned that virtualisation will take away from the handcraft or the hands-on experience of working with materials and hand sketching. They may perceive this as undermining their identity and the authenticity of their craft.
   - **Brand identity and consumer expectations:** In sectors like luxury and haute couture, craftsmanship is integral to brand identity. The use of high technology may be viewed as incongruent with the preservation of this image, leading some consumers to oppose technology in design and product development.
2) **Industry attitudes reflect Arts and Crafts Movement ideals:** Once more, a desire to widen access for all to enjoy art and craft is evident as a reason to adopt virtual enabling technology.

The resistance the PhD participants encountered from designers revealed an intriguing discussion. As highlighted in the literature review, the fashion industry has historically resisted new technologies. This resistance is often driven by fear of change and the misconception that virtualisation will replace designers. While certain roles will be lost to automation, it does not necessarily mean the removal of 'craft' or the craft person. All participants agreed that skilled practitioners remain essential to maintaining craft and authenticity. Their roles will evolve, potentially merging with technical design roles. Therefore, virtualisation will directly impact designers, challenging them to adapt to the industry's ongoing transformation.

Furthermore, resistance to 3D design software often stems from a lack of understanding. The empirical research revealed that upper management teams and fashion designers frequently misunderstand 3D design software and its intended use. One common misconception is that 3D design software is an all-encompassing solution. Another is the belief that 3D design software functions as artificial intelligence. In reality, the software relies on input from the designer and does not design autonomously. Generative design was briefly discussed during the data collection, with participants expressing strong scepticism about using this technology to replace designers.

In comparison to other industries, the tactile element is more important in the fashion design and product development process. Therefore, the concern of eliminating tactile elements such as feeling the fabric or hand sketching is a reason to resist. A designer's craft is influenced by their authentic expression and creative process, making virtualisation appear as a threat to their identity. However, designers are often describing the creative process rather than the product development process. The use of virtualisation is not asking practitioners to give up their creative process but to consider it as a separate stage.

Overall, most participants believe virtualisation supports concepts of craft and authenticity, as it allows stakeholders to visualise design intent and experiment with various materials and design ideas in real time. However, it will challenge the designer or craft person adopting virtual technologies within their process. As discussed in the craft literature, craft evolves with the times.

Lastly, current themes of inclusivity, decentralisation, and customer participation in the design process echo those of The Arts and Crafts Movement, which arose in response to industrialisation in the First Industrial Revolution. Similarly, the discourse between technology and social values is prevalent with the emergence of virtual technologies and The Fourth Industrial Revolution, Industry 4.0. This correlation is significant as it highlights the long-standing discourse on the role of humans amidst the continual advancement of technology. By understanding this conflict, managers can alleviate fears by clearly defining the role of virtual technologies as tools. Change management, often discussed during the data collection, should focus more on the human element when strategically planning to implement new technologies.

11.2 Contribution to knowledge

The PhD research significantly contributes to knowledge by offering new insights into virtualisation within the fashion industry. The study combines theoretical humanities with applied science, providing a comprehensive academic analysis of the industry's adoption of virtual technology in the product development process. The study contributes to knowledge in the following ways:

1.) Provides empirical insights through three methods: surveys, interviews, and case study research.

2.) Clarifies the conceptual reality of the uptake and application of virtual technologies in the fashion industry.

3.) Demonstrates practical evidence of virtualisation applications beyond entertainment, demonstrating viability within back-end operations.

4.) Establishes a foundation for understanding terminologies and processes, allowing future researchers to build upon.

5.) Differentiates between marketing narratives and real-world applications, identifying practical challenges and opportunities.

By adopting an interpretivist stance and ethnographic approach, this study provides a practical perspective on virtual technologies and their application within contemporary industry. It provides clarity on the uptake of virtual technology and presents practical evidence of its applications in a commercially viable way, moving beyond mere entertainment uses and theoretical studies.

Additionally, the study examines how digital technologies are integrated into processes and fit within a streamlined digital thread. It addresses concepts such as Industry 4.0, mass customisation, circularity, and social responsibility, exploring their feasibility and how they are often used interchangeably, leading to confusion. The study critically analyses the blurred lines between marketing claims and reality, distinguishing between genuine advancements and digital utopias that lack rigorous scientific research. Therefore, this study enhances the understanding and contextualisation of virtualisation, pushing the industry's understanding forward.

11.3 Limitations of PhD study

All research methods have limitations (Ross and Bibler Zaidi, 2019). This PhD study acknowledges these limitations, particularly concerning the survey. Although the survey is limited in detail and number of respondents, it successfully identified key respondent groups for the subsequent phases of the methodology, provided foundational insights into the research question, and served as a recruitment tool for the interviews. Furthermore, the study utilised three distinct methodologies, which collectively facilitated a thorough approach to data collection and analysis.

In addition, the time allocated for the case study research was constrained by budget and scheduling limitations. Nevertheless, the case study organisations are planning to extend the implementation of virtualisation to other areas of their business. This creates opportunities for follow-ups studies or new observations in future research. The research participants have shown interest in future collaborations.

Another potential limitation is the lack of diverse perspectives – particularly from participants who are critical of 3D design technologies. Initially, recruiting participants for interviews and the survey who was interested in the technology was more straightforward than finding those with opposing viewpoints. One speculation for this is the ambiguity and limited understanding surrounding the subject at the start of COVID-19. For instance, one survey respondent initially agreed to an interview but later hesitated, expressing concerns about their own knowledge on the topic. Despite reassurances, this respondent chose not to participate.

Although there is a personal interest in virtual technologies, most participants raised critical discussions. While the empirical research does not fully represent the industry as a whole, the majority of the industry is at the start of adopting and implementing virtual technologies. Some participants estimate that less than 10% of the industry has thus far explored 3D design technology and virtualisation. Nevertheless, the PhD study documents the initial steps in the adoption curve, offering a foundation for future planning and analysis.

11.4 Further research

The PhD findings reveal several promising avenues for future research. The study highlighted the need for a multi-disciplinary approach, incorporating fields such as data science and computer science, to advance virtualisation in the fashion industry. As previously discussed, the fashion industry is entering a new phase with the adoption and implementation of 3D design technologies, which presents numerous challenges and obstacles. Therefore, there are many opportunities for further research to observe how virtualisation will impact on other stakeholders and regions within the value chain. In addition, further studies in Business Process or Operation Management are necessary to optimise virtual technologies and processes throughout the value chain.

The study also paves the way for further investigation into how 3D virtual assets and 3D design technologies can be utilised within the value chain beyond design and product development. For Companies 1 and 2, from the case study research, the next step in their digital transformation journey is integrating virtual technologies into production. Many participants observed that 3D virtual modelling is not yet used 'end-to-end', unlike in other product industries. This gap is particularly pronounced in the fashion industry, which is complex due to cultural, political, and social dynamics of the global fashion supply chain.

In regard to Industry 4.0, the theoretical paradigm presents numerous themes for further research, such as open-source fashion, smart factories, and decentralised fashion systems. The research findings indicate a lack of empirical research on Industry 4.0 and the technological discourse in the fashion industry. Furthermore, the correlation between virtualisation and environmental impact needs further critical and objective observation. While technology is considered a key solution for some of fashion's most pressing issues, it could potentially lead to further negative outcomes. Alternatively, adopting a more humanitarian approach and shifting cultural values may yield more effective and sustainable outcomes.

Furthermore, fashion curricula in higher education should be reevaluated to better prepare students for an increasingly technical and technology-driven industry. Academia must evolve to align with contemporary industry practices. Future research should explore how fashion educators can adopt innovative pedagogical methods to engage students with new technologies and develop critical, forward-thinking skills essential for industry advancement. Additionally fostering collaboration, communication, and empathy among peers, as well as between academia and industry, is crucial for effective educational and professional development.

11.5 Concluding remarks

Conducting this research not only led to significant findings but also broadened my perspective and fostered personal growth. The findings challenged preconceived notions regarding the potential impact of virtualisation on product development. While initial discussions with research participants focused on virtualisation and technologies, they often shifted towards social factors, emphasising the human component. Many participants highlighted the importance of change management, investing in stakeholders, and prioritising social responsibility over profit. The fieldwork led to a deeper understanding of how culture, values, and ethics significantly shape organisations and the industry.

Moreover, the research also fostered a greater appreciation for suppliers, product developers, and production teams whose craft, skill, and expertise turn a designer's art into tangible products. Despite their crucial role, their contributions often go unnoticed. This study underscores the need to consider the impact of virtualisation on all stakeholders, acknowledging the power dynamics where brands may compel suppliers to adopt compatible technologies.

Virtualisation has the potential to reshape the industry for the common good, but also poses risks of further negative social and environmental impacts. To fully gain the benefit of virtualisation and digital technologies, there is a great deal of foundational work needed before scaling practical application in industry. The fashion industry will need to construct a strong IT foundation, rethink the way garments are designed and produced *across* the value chain, and seek external expertise from multiple disciplines. Moreover, the industry must embrace new possibilities, share knowledge, and be willing to take risks to transform into a more effective and innovative industry. While there is a positive outlook and anticipation for new technologies in the fashion industry, maintaining an objective perspective is crucial moving forward. Technology alone is not a solution. However, a systematic shift of social values and educational approaches is essential for meaningful industry change.

Appendices

The following appendices are provided in this section:

- Appendix A: Academic Studies
- Appendix B: Survey
- Appendix C: Results of Survey
- Appendix D: Interview Questions Route
- Appendix E: Interview Participants' Job Roles
- Appendix F: Case Study 1
- Appendix G: Case Study 2
- Appendix H: Case Study 3
- Appendix I: Digital Product Creation Pathway
- Appendix J: Ethics Application
- Appendices

Appendix A: Academic Studies

Study and date: Papahristou, E & Bilalis, N. (2017)

Title: 3D virtual prototyping traces new avenues for fashion design and prototyping development: a qualitative study."

Research focus: Analyses the current state of 3D virtual software solutions and the adoption and implementation of early adopters for 3D prototyping considering barriers, challenges, and opportunities.

Method(s) used: Interview research (unstructured)

Industry of focus: Fashion

Department: Within the school of production, engineering, and management

Country of focus: Global industry – 12 countries in total

Document type: Journal Article

Note: Available before 2020

The purpose of this article highlights the digital transformation phenomenon in regard to the fashion industry. Furthermore, the study examines information technologies as a key component to digital transformation and creating a framework for the fashion industry. A case study was the chosen method to examine the implementation of product lifecycle management (PLM) of a small fashion house. This study is aimed at fashion practitioners to provide a framework on how to incorporate digital technologies within their current business and understand their benefits.

As the authors state in the limitations, this study consists of only 1 case study. In turn my PhD study supports their findings in regard to the attitudes and the theme of 'craft' with designers as well as technology vendors should be aware a lack of understanding of technology is a barrier. As one of the earlier researchers on this topic, more has developed. In this paper, the authors refer to 'digital technologies' as IT and technologies which define Industry 4.0 as 'digital transformation'. (Which shaped my early understanding of digital transformation.) The paper feels quite broad despite the focus on PLM. Digital transformation phenomenon will lead to the creation of new capabilities within companies". P. 6 3D technology is one of the technologies mentioned. The authors discuss the literature is scarce in regard to the digital transformation phenomenon. They have described end-to-end in the context of connecting all stakeholders throughout the value chain as well as highlighting the importance of partnership and collaboration.

I also found a disconnect with the industry, as many of the participant's did not reference digital transformation in regard to the themes presented such as globalisation. Also, digital transformation in the context of Industry 4.0 is to be in the area of manufacturing. The article still only discusses the design process, but not through to production. In addition, the participants have only experimented in prototyping accessories and footwear– not apparel. Also, this is a small company, how to scale and what this looks like is missing as well as the impact on the suppliers. In addition, the article does not specify what product it is, but assuming it is a footwear and accessories prototype. In addition, the 'task' in which participants would be undertaking is not clearly stated.

Study and date: Alfaro and Arribas, (2016).

Title: Digital transformation of a small fashion house: a PLM implementation

Research focus: To explore digital transformation, key roles of information technologies, and Product Lifecycle management (PLM) in the fashion industry. Key themes: Digital transformation, technology implementation, product lifecycle management.

Method(s) used: Inductive Case Study

Industry of focus: Fashion industry– Haute Couture

Country of focus: France

Document type: Journal Article

Note: Available before 2020

In Alfaro and Arribas (2018), the purpose of the research is to demonstrate how value can be added using 3D digital technology throughout the value chain alongside challenges industry professionals will face for the fashion industry. This study includes a case study following the experience of an haute couture fashion designer to develop a “luxury footwear collection” using 3D digital technologies throughout the design and production stages for the showcase of the line through a pop-up shop.

According to the authors, further literature on the experiences of designers and brands using 3D technology in their working environment is needed. The case study demonstrated a framework of designing in 3D, prototyping in 3D, and using 3D printing. This study was based on the creation of a trainer rather than a garment. Although trainers are a fashion commodity, the steps during the production cannot be compared in the same way as a garment.

Same as above, the study is dated, and the themes are discussed in a general way despite the focus is on 3D digital technology. In addition, the study refers to digital transformation in regard to Industry 4.0; however, once more not addressing production. Moreover, the article does highlight that few companies are using 3D design technology 'successfully'. The authors have found a lack of literature around the practicalities of the technology in addition to the designer and 3D digital technology within the creative process. Once again only focusing on footwear. The study uses '3D digital transformation' this process is called digital product creation (DPC). The study does discuss 'virtual twin' to be exactly as it is in the physical world. Once again, the 3D printed… not able to scale this for garments. Once more, empirical research as the literature is lacking.

Study and date: Azhar Iqbal, M. (2013).

Research focus: Azhar Iqbal, M. (2013). *Virtual Product Development and Management Opportunities in Fashion Industry* (Master's Thesis) keywords virtual, CAD, PLM.

Method(s) used: semi-structured interviews for case study, literature (No field work or observation of the phenomenon in its environment– only interviews)

Industry of focus: Fashion Industry

Field of Study and Award: Master's thesis in the school of Material Science MS

Country of focus: general fashion industry. – Mexico, Germany, China, Israel,

Adidas in 2004–2006

Note: Available before 2020

This study is similar to my PhD Study in the sense that it focuses on fashion design and digital prototyping. However, the master's thesis does not critically consider the actual representation of the industry and rather predicts the opportunities it can bring. This is another way my literature contributes to this area of research. However, the study is dated. Furthermore, the focus is on 3D modelling, but not fully thinking in regard to Industry 4.0 and the potential of even further development of the whole process.

The way in which the author discusses the design process as if the designer who is the 'artist' p.6 carries out design and product development utilising 3D design technology, pattern digitiser, and pattern making. The author does not acknowledge that there are multiple designers who carry out these tasks. Also speaks as if virtualisation and 3D is used in the industry as if all companies are doing this; however, this is an assumption and no evidence of the general industry. In addition, the empirical research only interviews six participants.

Study and date: Papahristou, E & Bilalis, N. (2017). “3D virtual prototyping traces new avenues for fashion design and prototyping development: a qualitative study.” *Journal of Textile Science and Engineering.* 7(2), pp. 1-6. doi: 10.4172/2165-8064.1000297

Research focus: Analyses the current state of 3D virtual software solutions and the adoption and implementation of early adopters for 3D prototyping considering barriers, challenges, and opportunities.

Method(s) used: Interview research (unstructured)

Industry of focus: Fashion industry within the school of production, engineering, and management

Country of focus: Global general industry – 12 countries in total

Note: Available before 2020

The qualitative study investigates the implementation of digital prototyping of early industry adopters during the design, development, and production stages in regard to the garment sector of the fashion industry. Furthermore, the researchers observe the level of implementation of digital prototyping and the opportunities and barriers in which it can succeed as a standard process to increase business productivity. The study highlights the manual driven nature of the industry and the slow transition to digital prototyping. The researchers suggest a further investigation on how vendors can support early adopters along the adoption and implementation process. The study is limited in data collection and unclear on methodology, but the authors state the findings are based on previous data prior to the study.

My study supports the study’s findings on the advantages, disadvantages, and challenges. They could have expanded on *'Big corporations applying pressure on the vendors'* needs to be acknowledged further in which my research has explored. In addition, the attitudes of the participants in which all participants are optimistic as well as a desire for the technology's uptake to be effective.

Study and date: Papahristou, E. (2016). *The Effective Integration of 3D Virtual Prototype in the Product Development Process of the Textile/Clothing Industry* (PhD Thesis).

Method(s) used: survey, personal interviews, and literature review

Industry of focus: Production engineering and management: Textile/clothing industry

Note: Available / not available in 2020

This study is very similar to my PhD study. However, this piece of work is dated, and much advancement in this process has taken place. The approach to methodology and the project objectives differ. Although this study does integrate both surveys and interviews, the research motives are different. My study looks more in depth of providing how the industry is integrating virtual technologies for future plans of development. Furthermore, the current state of the industry is different due to the pandemic; therefore, more organisations are approaching virtualisation differently by integrating digital technologies into the process. The focus of Papahristou’s study is on

3D virtual prototyping, whereas the interest for my PhD study is the virtualisation of the process rather than purely focusing on 3D prototyping technology specifically. Therefore, measuring the social constructs of the implications of digital tools such as 3D will aid virtualisation.

Interviewees were selected purposely rather than random. Four experts from different backgrounds in a survey and personal interviews. The methodology is not clear. The author started with the four interviews and literature then constructed the survey and further interviews, but it is unclear how many of each. Also, qualitative surveys which have certain limitations.

Study and date: Kaplandidou (2018)

Research focus: *Digitalization in the apparel manufacturing process* (Master's Thesis).

Method(s) used: Qualitative case study with 7 companies consisting of interviews. Only 13 interviews.

Industry of focus: Fashion industry in Masters of Innovation Science

Country of focus: Greece

Note: Available before 2020

The master's thesis explores digitalization as a competitive advantage for enterprises to meet business demands with a focus on the apparel industry in Greece. The aim of the research study looks at seven apparel manufacturing firms in Greece to identify "dynamic capabilities in digital transformation" and challenges. Furthermore, the study examines Industry 4.0 and the key technologies which make up the paradigm. The thesis does not focus on 3D prototyping for the industry, but highlights 3D design software as it is changing from a manual process to digital.

Digital transformation in regard to manufacturing and Industry 4.0 principles. Once again speaks as if these technologies are widely used within fashion manufacturing. There's a disconnect because most of these countries are in low-income countries. There is evidence of maybe some but not widespread. Once again lacks evidence of the change. Many terms, but not much process and it's in pieces, not fully adoption of all the technologies.

Study and date: Bertola and Teunissen (2018).

Title: Fashion 4.0. Innovating fashion industry through digital transformation.

Research focus: Projecting exploring the potential impact of Digital transformation to lead to Industry 4.0 for the fashion industry.

Method(s) used: Literature and Research Paper

Industry of focus: Fashion Industry

Country of focus: General Manufacturing Sector

Document type: Research paper

Note: Available before 2020

This article lays out a foundation of key themes for this PhD study and is used as the main source for the Industry 4.0 section provided in Ch.2 literature review: industry 4.0, digital technologies, virtualisation, restructuring the fashion industry, issues: environmental, design, craft, authenticity, creating new ways of fashion design.

The article provides a thorough investigation of Industry 4.0 paradigm trends and highlights key areas which have potential to impact the textile and garment industry. Furthermore, the researchers provide a general smart factory framework which includes the implementation of high technologies. As seen throughout other Industry 4.0 literature, the paradigm is a new area of study. Therefore, there is a need for further explored areas of research.

Santos, et al. (2020). “The virtualization of the fashion product.” Paper as part of a PhD study:

“*The influence of the Digital tools and Virtual Environments in human creativity and concept development in the specific case of fashion design products.*”

This article highlights evidence of current exploration with virtual technologies and how the fashion industry is using them for the creation of virtual fashion products (i.e. virtual garments and collections, augmented reality, virtual reality, virtual prototyping, etc.) Furthermore, the paper examines the impact virtual products have on the role of the fashion designer and society.

Appendix B: Survey question route

Virtualisation of Product Development Process in the Fashion Industry – Survey

Welcome to my survey!

I'm Logan McCage, a PhD research student at the University of Salford, UK. This survey forms part of my doctoral research study.

The purpose of this survey is to better understand how virtualisation of the product development process is impacting the Fashion and Apparel / Garment Industry. My research seeks to understand the processes by which the industry is undertaking virtualisation.

The final survey will be analysed, and the results presented in my doctoral thesis. However, I'd be happy to send you the summary Survey Report if you would be interested. To receive this, please complete the relevant section at the end of the survey.

Your responses to the questions in this survey are completely confidential. All information that you kindly provide will be held in the strictest confidence and used only for statistical analysis. All responses will be anonymised, and you will not be personally identifiable from anything you say. Your participation in this survey is voluntary, so you may drop out at any time without penalty.

If you have any questions regarding the survey, wish to access the data you provide or wish to withdraw your data from this research, please contact me by email at l.mccage@edu.salford.ac.uk

---

INSTRUCTIONS

This survey should take around **10–15 mins** to complete. A progress bar at the top of each page indicates your position as you move through the survey. You can leave the survey at any time by simply closing the survey window — all your answers will be saved.

Please complete this survey before the end of Tuesday 3 August 2021.

1.) I consent to participating in this research and to the use of my survey responses as described above. I confirm that I understand the purpose of the study and that I can withdraw from the study at any time, without penalty.

By checking the 'Yes' box below you are confirming that you have read the description of the study and that you agree to the terms as described. Required

- Yes
- No

Information: What is virtualisation?

Virtualisation is the process of creating a 'virtual' (i.e. computer-based) model of a physical object. This is related to digitalisation, which is the conversion of text, images or sound into a digital form that can be processed by a computer and support daily tasks.

2.) Please indicate the extent to which you agree with the following statement: Virtualisation is a worthwhile investment for the fashion industry.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don’t know/ not applicable

Section 1: Your use of 3D design and prototyping technology

Information: What is 3D design technology?

3D design technology allows the creation of computer-based three-dimensional models of design proposals to support decision-making around production and other business processes.

3.) Does your company currently use 3D design technology?

- Yes
- No

4.) How long has your company used 3D design technology?

- Less than 12 months
- Between 1 and 5 years
- Between 6 and 10 years
- Over 10 years

3D prototyping technology

Information: What is 3D prototyping technology?

3D prototyping technology uses an interactive digital model of a garment to allow for rapid design changes without the need to create physical prototypes or samples.

5.) Does your company currently use 3D prototyping technology?

- Yes
- No

6.) How long has your company used 3D prototyping technology?

- Less than 12 months

- Between 1 and 5 years
- Between 6 and 10 years
- Over 10 years

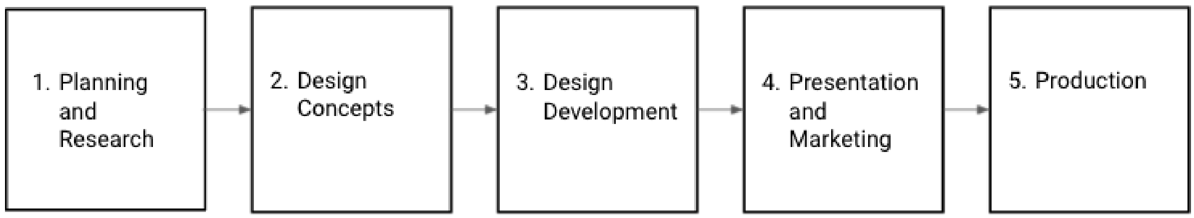
7.) What 3D software does your company use? (Please tick all that apply)

- CLO Virtual Fashion Design
- Browzwear: VStitcher
- Lectra: Modaris
- Gerber: AccuMark
- Other

If you selected Other, please specify:

Use of 3D technology in product development

When answering the following question, please consider how your company's development process maps onto the five stages of the generic product development process shown below:



The Five Stages of the Fashion Product Development Process

(Adapted from Senanayake, 2015)

8.) At which stages of the product development process do you use 3D design technology? (Please tick all that apply)

1. Planning and Research
2. Design Concepts
3. Design Development
4. Presentation and Marketing
5. Production
6. Don’t know
7. Other

If you selected Other, please specify:

9.) At which stages of the product development process do you use 3D prototyping technology? (Please tick all that apply)

1. Planning and Research

2. Design Concepts
3. Design Development
4. Presentation and Marketing
5. Production
6. Don't know
7. Other

Please indicate the extent to which you agree with the following statements:

10.) My company is seeking to extend its use of 3D prototyping technology to other stages of the product development process.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

11. Our manufacturers are generally willing to implement new technologies so they can integrate with technologies used by my company

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

12. Our retailers are generally willing to implement new technologies so they can integrate with technologies used by my company…

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

13. Incorporating 3D prototyping software and technology within my company's existing IT systems has been easy

- Strongly Disagree
- Disagree

- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

14. What issues have you experienced incorporating 3D prototyping software within your company's existing IT systems? Integrating 3D prototyping software… (Please tick all that apply) *Required.*
    - …with management software was not supported by our IT system.
    - …with Product Lifecycle Management (PLM) software was not supported by our IT system.
    - …with Enterprise Resource Planning (ERP) software was not supported by our IT system.
    - …was not supported by our hardware systems.
    - …prevented access to files created in different software
    - …caused miscommunication of garment information with retailer/ manufacturer
    - …caused no issues.
    - …caused other issues.

Please specify:

15. How does your company train employees in 3D design and prototyping software? (Please tick all that apply)
    - Training is provided in-house
    - Employees take university training courses (paid for by the company)
    - Employees take university training course (paid for by the employee)
    - Employees get face-to-face training from software providers
    - Employees get online training from software providers
    - No training is provided
    - Other

If you selected Other, please specify:

Section 2: Management

Information: **What are PLM and ERP software?**

Product Lifecycle Management (PLM) software includes tools that support planning, development, and production activities over the product life cycle.

Enterprise Resource Planning (ERP) software includes tools used to manage resources and improve business development activities.

16. What software do you use to manage the product lifecycle / product development process? (Please tick all that apply)

- Microsoft Excel
- Product Lifecycle Management (PLM) software
- None
- Other

If you selected Other, please specify:

17. Product Lifecycle Management (PLM) software is a worthwhile investment

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don’t know/ not applicable

18. Enterprise Resource Planning (ERP) software is a worthwhile investment

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don’t know/ not applicable

19. Is your company currently undertaking digital transformation?

- Yes
- No
- Don’t know/ Not applicable

20. Approximately when will your company's digital transformation be complete?

- In less than 1 year
- In 1-2 years
- In 2-5 years
- In more than 5 years
- Don’t know
- Other

21. Does your company plan to undertake digital transformation within the next five years?

- Yes
- No
- Don’t know/ Not applicable

Please indicate the extent to which you agree with the following statement:

22. Digital transformation is a worthwhile investment

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

Section 3: Impact of the COVID-19 Pandemic

Please indicate the extent to which you agree with the following statements:

23. The COVID-19 pandemic has resulted in increased use of 3D prototyping technology by my company

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

24. The COVID-19 Pandemic has accelerated our longer-term plans to adopt the use of 3D prototyping technology

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree
- Don't know/ not applicable

Section 4: About your company

25. In what sector of the industry does your company specialise?

- Textile manufacturing
- Apparel/ Garment manufacturing
- Fashion design
- Retail
- Software development

- Fashion design consulting
- Retail consulting
- Other

Please specify:

26. Where is your company based?

[Drop Down Menu]

Section 5: About you

27. What is your role within your company? (Please tick all that apply)

- Manager
- Director
- Consultant
- Fashion designer
- Technical designer
- 3D artist
- Print designer
- Textile designer
- Buyer
- Merchandiser
- Technology software vendor
- Business development
- Entrepreneur
- Research and development
- Other

If you selected Other, please specify:

28. What is your gender?

- Male
- Female
- Other
- Prefer not to say

29. What is your age?

- 18-24 years

- 25-34 years
- 35-44 years
- 45-54 years
- 55-64 years
- 65 years or over

30. Thank you so much for your responses. If there are any comments you would like to add regarding the issues raised in this survey, please feel free to add them below.

31. Survey Report When the survey has closed, all responses will be analysed, and the findings compiled into a short report. If you would like to receive a copy, please provide your email address below.

Next Steps– Interview research

The results of this survey inform my interview research. Would you be willing to participate in a short (approx. 30 minute) telephone /video interview to discuss some of the issues raised in this survey?

If you would, please provide a contact email address and your name below– thank you!

Appendix C: Results of Survey

1.0 Introduction

Appendix C presents a summary of the findings of the survey conducted as part of this doctoral research.

1.1 About the Respondents

In this survey, (x35) respondents took part in the research: (x13) Male, (x21) Female, (x1) Prefer not to say. The age of the respondents include: (x10) 25-34 years old; (x7) 35-44 years old; (x12) 45-54; (x6) 55-64. The respondents represent a variety of perspectives from different countries including: (x2) China; (x1) France; (x7) Germany; (x1) Greece; (x1) Hong Kong; (x1) Italy; (x2) Sweden; (x9) United Kingdom; (x10) United States; (x1) Other (Multinational).

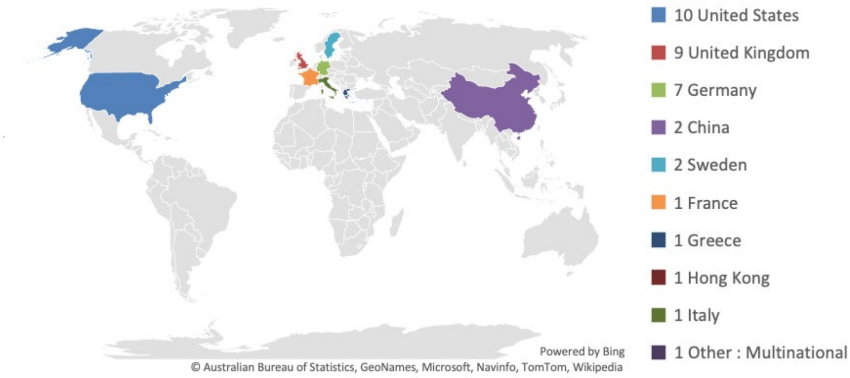


Figure C1 Countries of survey respondents

Respondents represented a range of experts in a variety of sectors within the Fashion/ Garment Industry. Roles of the respondents include: (x8) Managers; (x13) Directors; (x3) Consultants: (x3) Fashion designers; (x4) Technical designers; (x4) 3D artists; (x1) Textile designer; (x1) Buyer; (x2) Technology software vendors; (x2) Business development; (x2) Entrepreneurs; (x4) Research and development. Other roles include: (x1) Researcher; (x1) Educator; (x1) Chief Technology Officer (CTO); (x1) Project manager; (x1) Seamstress; (x1) Student.

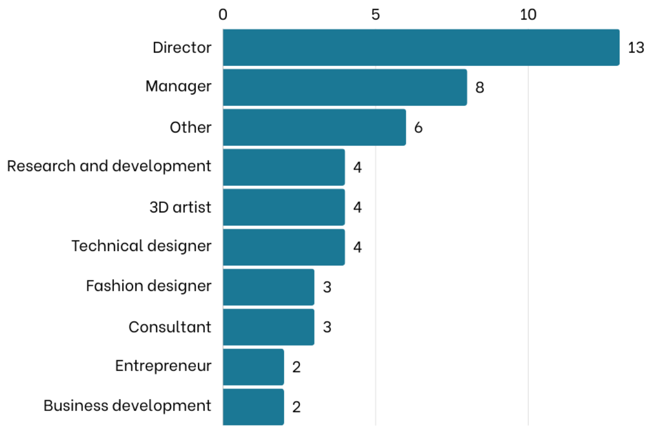


Figure C2 Roles of Respondents

Sectors of the industry where respondents work include: (x1) Textile manufacturing; (x9) apparel/garment manufacturing; (x6) Fashion design; (x3) Retail; (x2) Software development; (x4) 3D Fashion design consulting; (x1) Retail consulting. Other sectors include: (x1) Footwear, (x4) Higher education; (x1) 3D Digital Product Creation (DPC); (x1) Sourcing; (x1) Alterations and repairs.

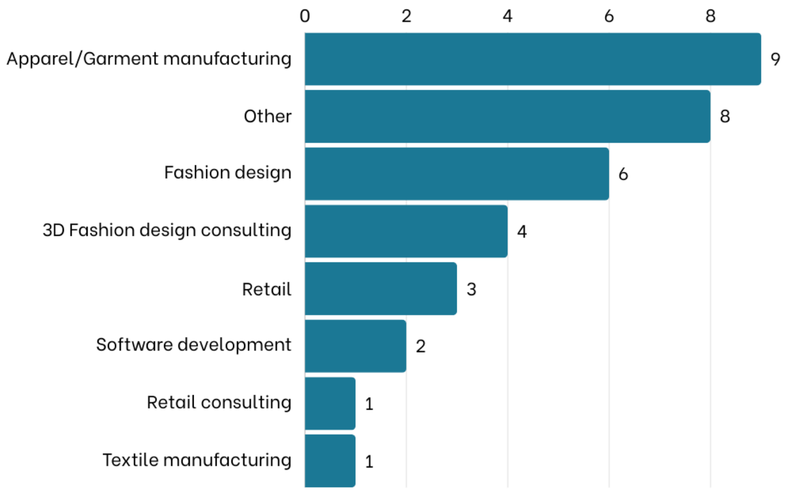


Figure C3 Sectors of the Industry

2.0 Results

The survey is divided into four sections:

- 2.1 Virtualisation
- 2.2 Section 1: Your Use of 3D design and prototyping technology
- 2.3 Section 2: Management
- 2.4 Section 3: Impact of COVID-19 pandemic

2.1 Virtualisation

Information: *What is virtualisation?*

Virtualisation is the process of creating a 'virtual' (i.e. computer-based) model of a physical object. This is related to digitalisation, which is the conversion of text, images or sound into a digital form that can be processed by a computer and support daily tasks.

Respondents were asked if virtualisation is a worthwhile investment for the fashion industry. The response was mostly positive with the majority of the respondents (19) Strongly agreeing and (12) agreeing. Out of the 35 respondents, only (3) Strongly disagreed and (1) Don’t know/not applicable. None of the respondents disagree or neither agree nor disagree.

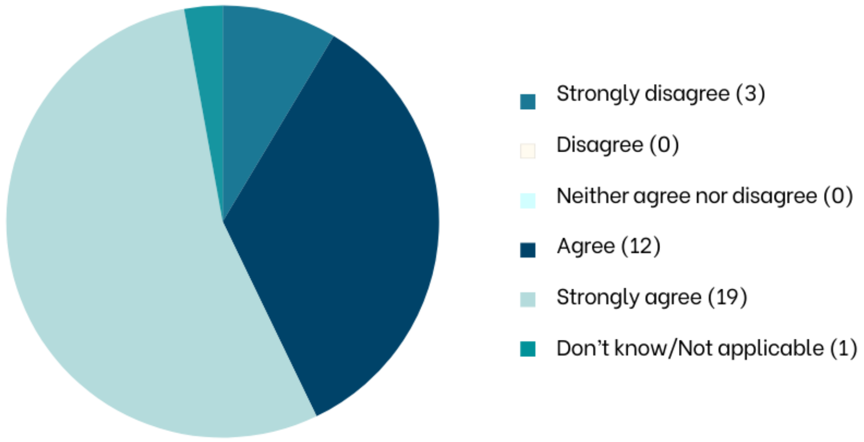


Figure **C4** Virtualisation a worthwhile investment

2.2 Section 1: Your Use of 3D design and prototyping technology.

Information: *What is 3D design technology?*
3D design technology allows the creation of computer-based three-dimensional models of design proposals to support decision-making around production and other business processes.

Respondents were asked if their company is currently using 3D design technology. With regards to the question, most of the respondents say their company is using 3D design technology (x28 respondents), while (x7) respondents said they are not currently using the technology.

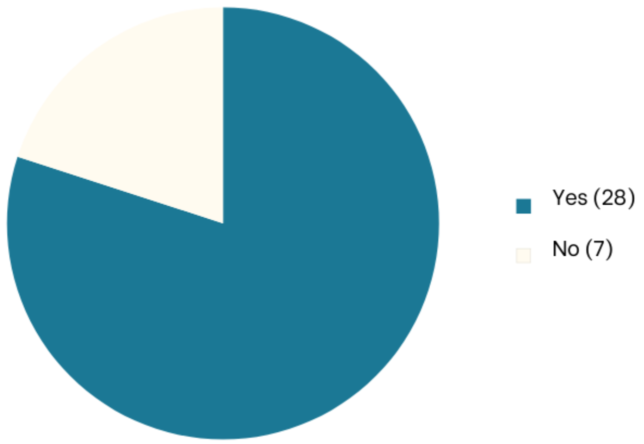


Figure C5 Current Use 3D design technology

When asked how long their company has used 3D design technology, the majority of respondents (x16) out of the (x28) respondents have used the technology Between 1 and 5 years while (x5) respondents have been using the technology for Less than 12 months.

There were only (x3) respondents who have been using the technology Between 6 and 10 years, and only (x4) respondents Over 10 years have been using the technology.

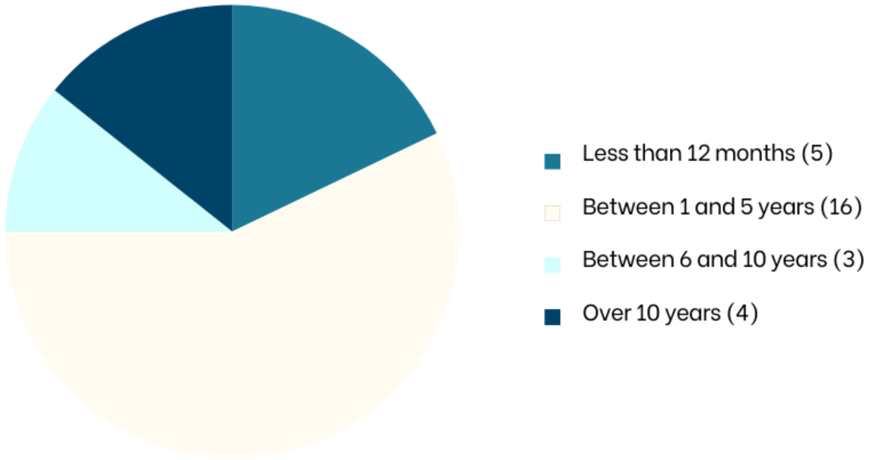


Figure C6 Use of 3D design technology

Respondents were then asked if their company currently uses 3D prototyping technology, most of the respondents (x25) said 'Yes' while only (x10) respondents said 'No'.

Information: *What is 3D prototyping technology?*

3D prototyping technology uses an interactive digital model of a garment to allow for rapid design changes without the need to create physical prototypes or samples.

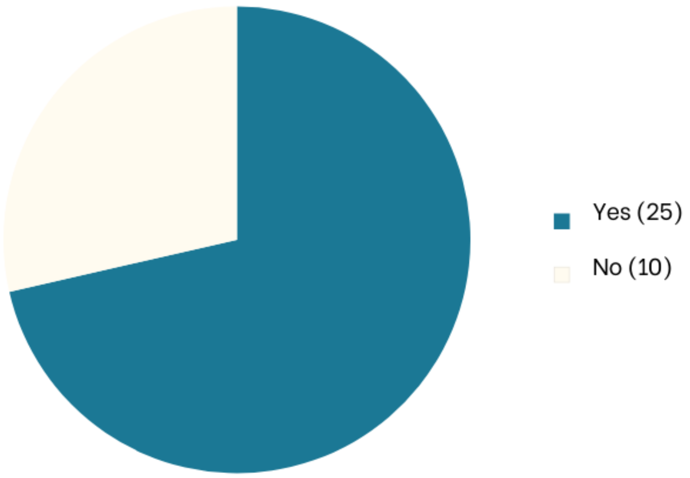


Figure C7 Current use of 3D prototyping technology

Respondents were asked how long their company has been using 3D prototyping technology. Most respondents are relatively new to using the technology with (x13) respondents saying Between 1 and 5 years, and (x6) respondents only using the technology for Less than 12 months. Only (x3) respondents have used the technology Between 6 and 10 years and (x3) Over 10 years.

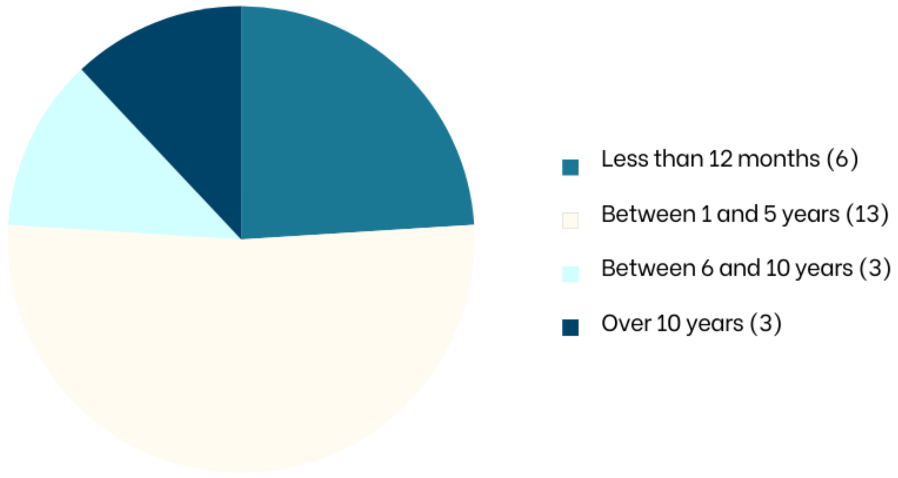


Figure C8 Use of 3D Prototyping Technology

Respondents are asked what 3D prototyping software their company uses. The survey found that most of the respondents use multiple 3D software with the most used being CLO Virtual Fashion Design Software (x14) respondents and Browzwear: VStitcher (x11) respondents. Other 3D software that were commonly noted were: Optitiex (x4); Blender (x4); Lectra: Modaris (x3); Modo (x3); Gerber: AccuMark (x2); Keyshot (x2). Other 3D software noted included: Proprietary(x1); Substance (plug-in Blender) (x1); uses 3Ds Max (x1); Unreal Engine (x1); Rhino (x1); DressingSim LSX (x1); In-house generative technology using deep learning (x1). Only (x2) respondents did not know.

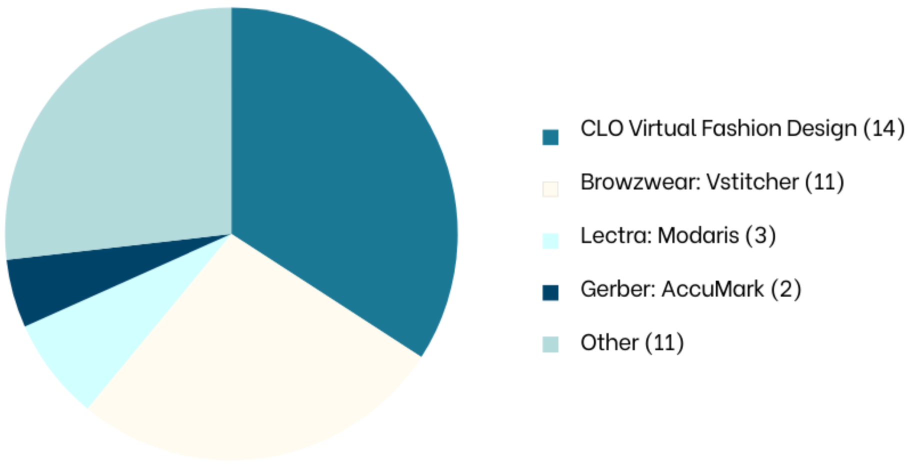


Figure C9 3D prototyping software

For the following questions (7 to 9), the respondents were asked to consider how their company's development process maps onto the five stages of the generic product development process shown below:

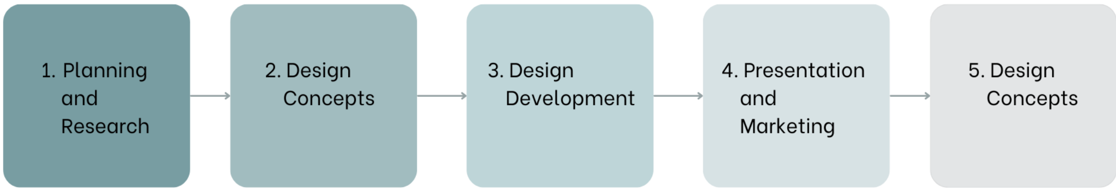


Figure C10 The Five Stages of the Fashion Product Development Process (Adapted from Senanayake, 2015)

Respondents were asked at which stage of the product development process their company uses 3D design technology and to select all that applied. Most of the respondents are using the technology during both Stage 2. Design Concepts (x20) respondents, Stage 3. Design Development (x21) respondents, Stage 4. Presentation and Marketing (x17) respondents. The areas where less used was during Stage 1. Planning and Research (x7) respondents and Stage 5. Production (x7) respondents.

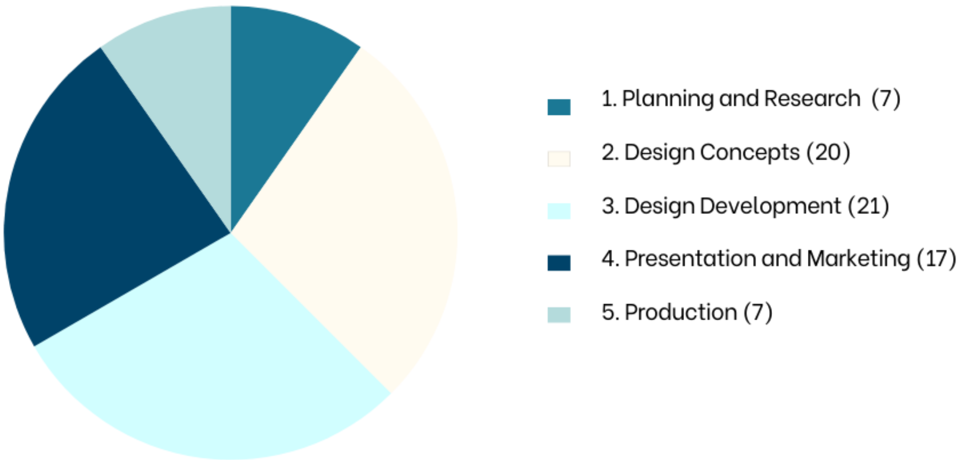


Figure C11 Use of 3D design technology during product development

Respondents were asked at which stages of the product development process does their company use **3D prototyping technology** as well to select all that applied. Interestingly, the technology had a variety of answers compared to the **3D design technology.** However, the most common stages that use the technology the most are still the same: *Stage 2. Design Concepts* (x15) respondents, *Stage 3. Design Development* (x22) respondents, and *Stage 4. Presentation and Marketing* (x10) respondents. The least used areas were during Stage 1. Planning and Research (x5) respondents and Stage 5. Production (x5) respondents. (x2) respondents Didn't know where the technology was used.

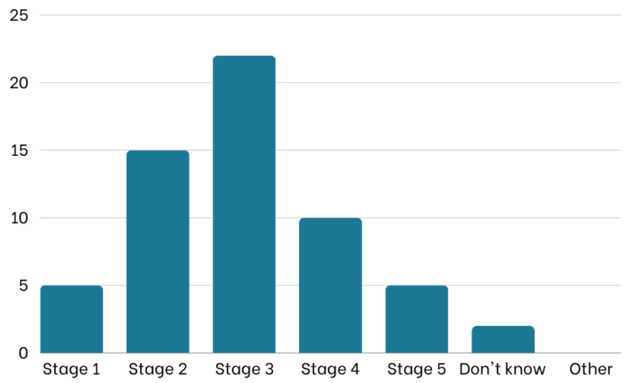


Figure C12 Use of 3D prototyping technology for product development

Following the previous question, respondents were asked if their company is seeking to extend its use of 3D prototyping technology to other stages of the product development process. Most of the responses was positive with most respondents Strongly agreeing (x9) respondents and Agreeing (x8) respondents. A few participants Strongly disagreed (x2) respondents and (x1) Disagreed. (x2) respondents Didn't know/ Not applicable.

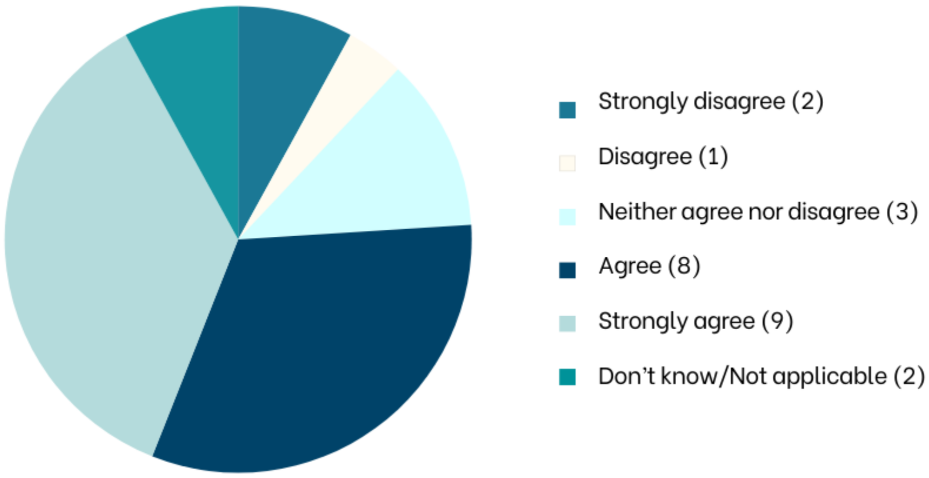


Figure C13 Extending 3D Prototyping Technology to Other Stages

Respondents were asked how generally willing their manufacturers are to implement new technologies so they can integrate with their company's technologies. Overall, the response was positive with most respondents (x10) Agreeing and (x2) respondents Strongly agreeing. However, the views of several respondents disagreed with (x2) Strongly disagreeing and (x5) Disagreeing. (x4) of the respondents Neither agree nor disagree while (x2) respondents Didn't know/ Not applicable.

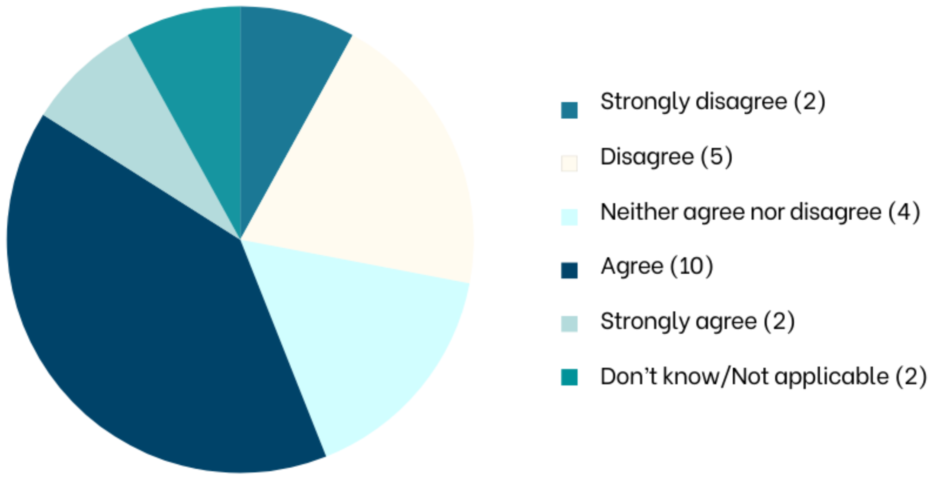


Figure C14 Manufacturers to Adopt New Technologies

The same question was asked however from the perspective of manufacturers. Respondents were asked how likely their retailers are generally willing to implement new technologies so they can be integrated by their company. In regard to the retailers, how likely they are to adopt new technologies to meet the needs of the manufacturer.

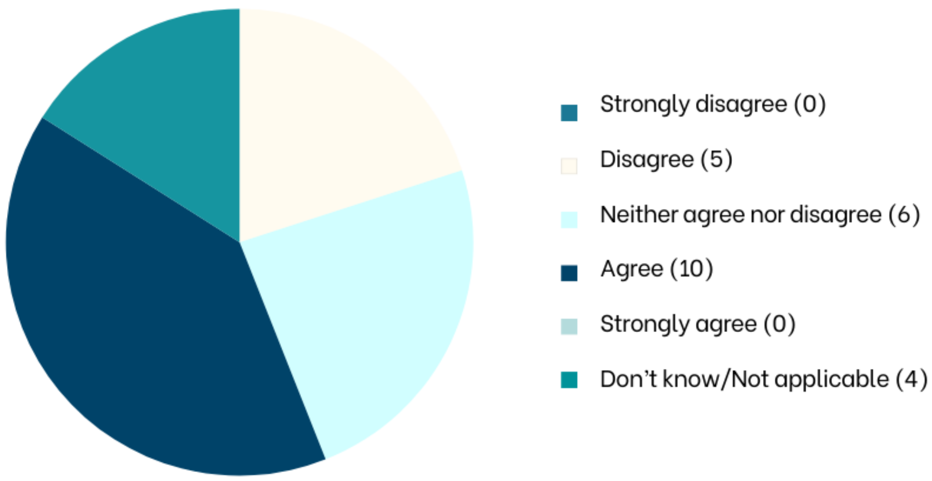


Figure C15 Retailers to Adopt New Technologies

The responses were not as certain as above and more even across the response range. Although the majority were slightly negative with (x5) respondents disagreeing and (x6) respondents Neither agree nor disagree. (x4) respondents Didn't know/ Not applicable. However, (x10) respondents agreed their retailers are generally willing to implement their technologies.

Respondents were asked how easy incorporating 3D prototyping software and technology within their company's existing IT system was. The response was mostly negative with most of the respondents (x6) Strongly disagree and (x9) Disagreeing. (x3) respondents Neither agree nor disagree while (x1) respondent Didn't know/ Not applicable. Only (x6) respondents Agreed and had a positive experience with incorporating the technology.

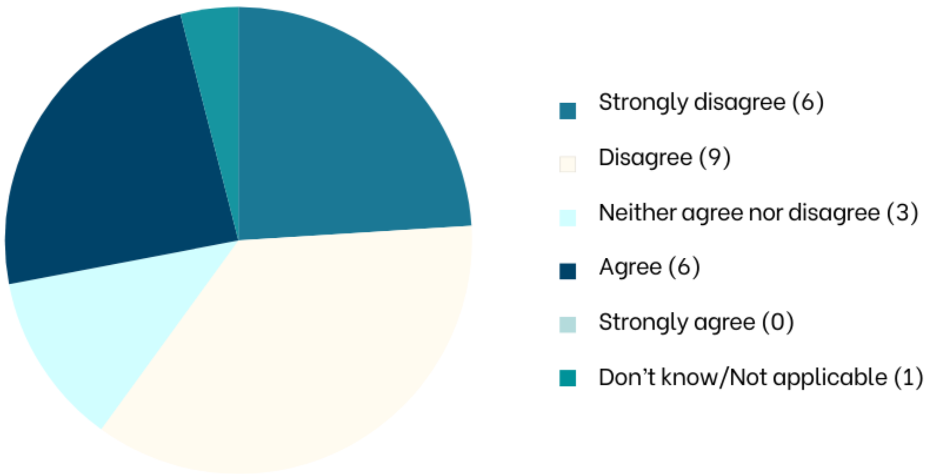


Figure C16 Incorporating 3D Prototyping Software

With regards to the previous question, respondents were asked what issues their company has experienced incorporating 3D prototyping software within their company's existing IT system. Respondents were asked to select all that applied. Respondent 70362 responded that the question did not apply to their company because the technology is not being integrated into their internal systems.

Integrating 3D prototyping software...	Number of Respondents
...with management software was not supported by our IT system.	11
...with Product Lifecycle Management (PLM) software was not supported by our IT system.	12
...with Enterprise Resource Planning (ERP) software was not supported by our IT system.	9
...was not supported by our hardware systems.	9
...prevented access to files created in different software.	5
...caused miscommunication of garment information with retailer/ manufacturer.	8
...caused no issues.	3
...caused other issues.	9

Table C1 Issues Integrating 3D Prototyping Software

Respondents were asked how their company trains employees in 3D design and prototyping software and to tick all that applied. The most common way of providing training from the responses was (x18) Training is provided in-house and (x12) Employees get online training from software providers. (x8) respondents selected Employees get face-to-face training from software providers. The least common choice was: (x3) Employees take university training courses (paid for by the company); (x2) Employees take university training courses (paid for by the employee); (x2) No training provided. One respondent selected 'Other' saying, "3D talent hired externally and already trained".

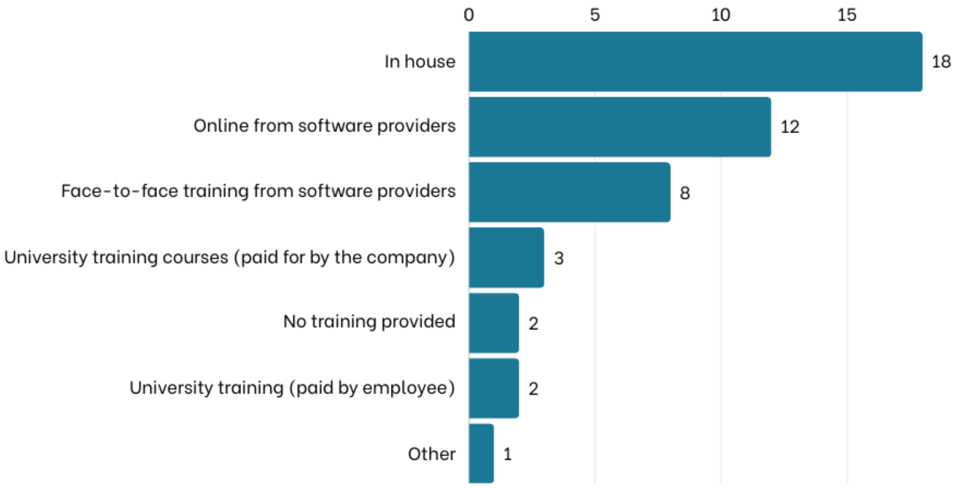


Figure C17 Training Employees

2.3 Section 2: Management

Information: *What are PLM and ERP software?*

Product Lifecycle Management (PLM) software includes tools that support planning, development, and production activities over the product life cycle.

Enterprise Resource Planning (ERP) software includes tools used to manage resources and improve business development activities.

Respondents were asked what software they use to manage their company's product lifecycle/ product development process and to select all that applied. Most of the respondents are using Microsoft Excel (x23) respondents to manage their product lifecycle/ product development process. Also commonly selected is Product Lifecycle Management (PLM) software (x19) respondents. Only (x9) respondents are using Enterprise Resource Planning (ERP) software and (x6) respondents are not using any software to manage their product lifecycle/ product development process.

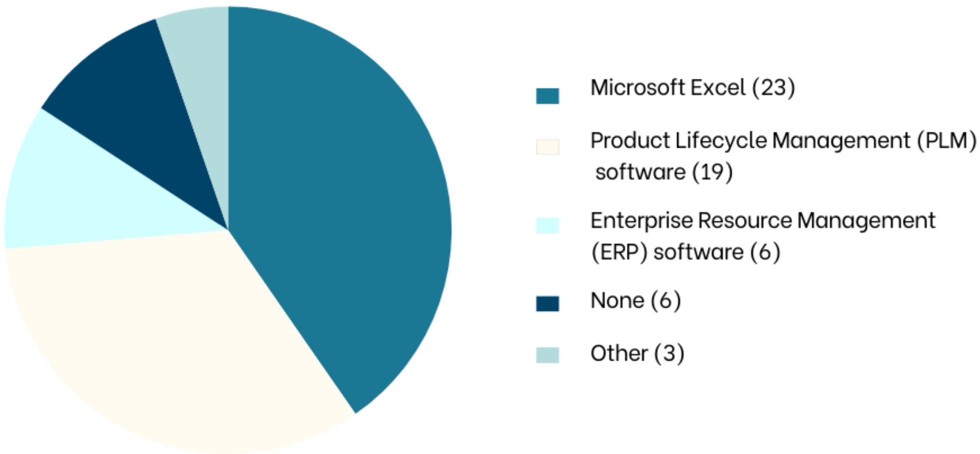


Figure C18 Management Software

Three of the 'Other' choices are PLM software: Flex PLM, ENOVIA, and Galaxius. Furthermore, some of the other selections are using a software that manages a variety of product lifecycle management tools. The term New Generation Computing (NGC) Software was given as an option to integrate multiple management tools into one platform. There are other software listed by respondents that are similar to this software solution: Trackvia and Asana. (x2) respondents need a new PLM solution.

The respondents were asked if Product Lifecycle Management (PLM) software is a worthwhile investment. Out of the responses, most of the responses were positive towards the software with (x14) respondents Strongly agreeing and (x10) respondents Agreeing. However, (x6) of the respondents felt differently with (x3) respondents Strongly disagreeing and (x3) disagreeing. Only (x2) respondents Neither agree nor disagree, while (x3) Didn't know/ Not applicable.

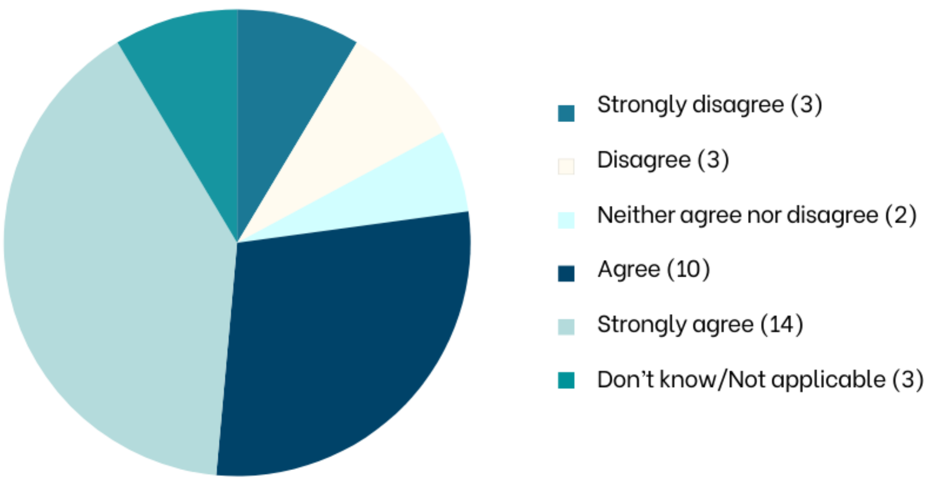


Figure C19 Product Lifecycle Management (PLM) Software

Following the previous questions, respondents were asked if Enterprise Resource Planning (ERP) software is a worthwhile investment. Once more, most respondents had a positive response towards the technology with (x4) respondents Strongly agreeing and (x16)

Agreeing. However, more respondents seemed indifferent about the software with (x7) respondents Neither agreeing or disagreeing; furthermore, (x7) respondents didn't know or was not applicable to them. Only (x1) respondent disagreed that Enterprise Resource Planning (ERP) software is a worthwhile investment.

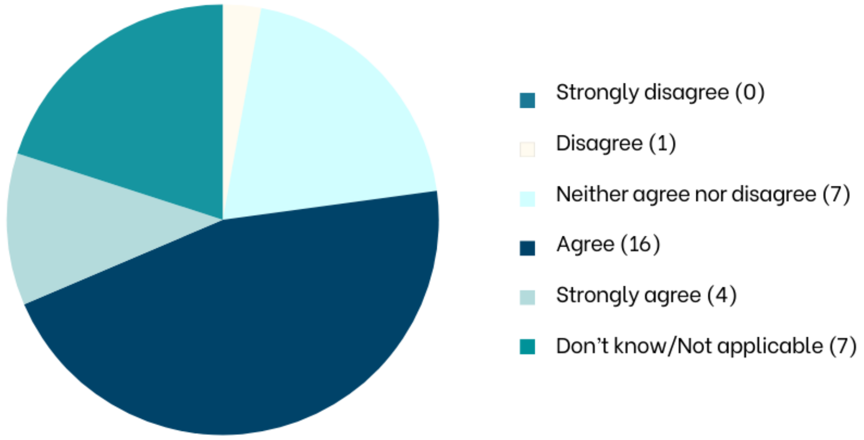


Figure C20 Enterprise Resource Planning (ERP) Software

> **Information:** *What is 'digital transformation'?*
>
> *Digital transformation* is the integration of digital technologies within all areas of a business, such as new product or service development, production, marketing, and sales. This may include the use of technologies such as 3D modelling and virtual reality.

Respondents were asked if their company is currently undertaking digital transformation. The majority, (x26) respondents, say their company is currently undertaking digital transformation while only (x5) respondents say they are not currently undertaking digital transformation. (x4) of the respondents didn't know or this question did not apply to them.

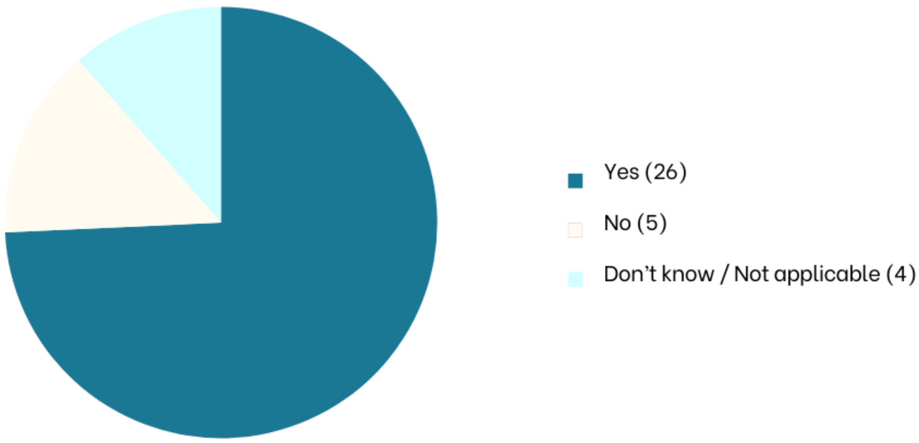


Figure C21 Digital Transformation

Following the previous question, I asked respondents approximately when their company's digital transformation would be completed. There were a variety of responses. Most of the respondents did not know when their company's digital transformation will be complete. However, most of the respondents said their digital journey will be completed within 5 years: (x5) In less than 1 year; (x4) In 1-2 years; (x7) In 2-5 years. Only (x3) respondents said In more than 5 years, and (x5) respondents selected 'Other'.

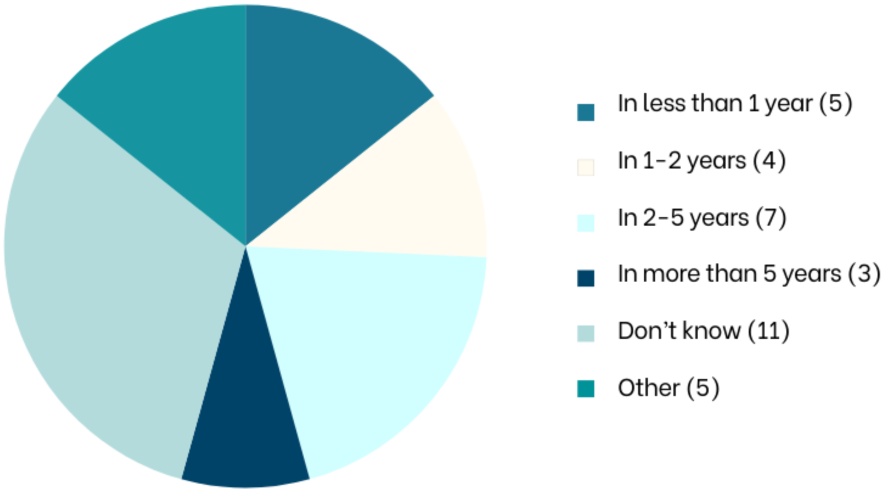


Figure C22 Completion of Digital Transformation

Respondents were asked if their company plans to undertake digital transformation within the next five years. The results were positive with (x24) respondents saying their company plans to undertake digital transformation within the next five years, while (x4) respondents say their company does not have plans to undertake digital transformation. Out of the (x35) respondents, only (x7) respondents didn't know.

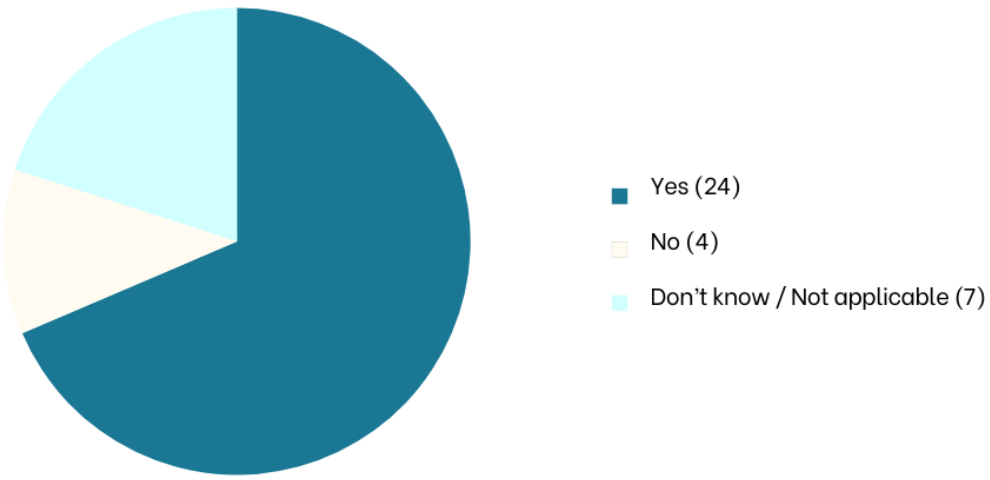


Figure C23 Undertaking Digital Transformation

Respondents were then asked if digital transformation is a worthwhile investment. The majority of the responses were highly positive with (x20) respondents Strongly agreeing and (x11) agreeing. Only (x1) respondent strongly disagrees, and no one disagrees. (x1) respondents neither agree nor disagree, and (x2) respondents didn't know, or it was not applicable.

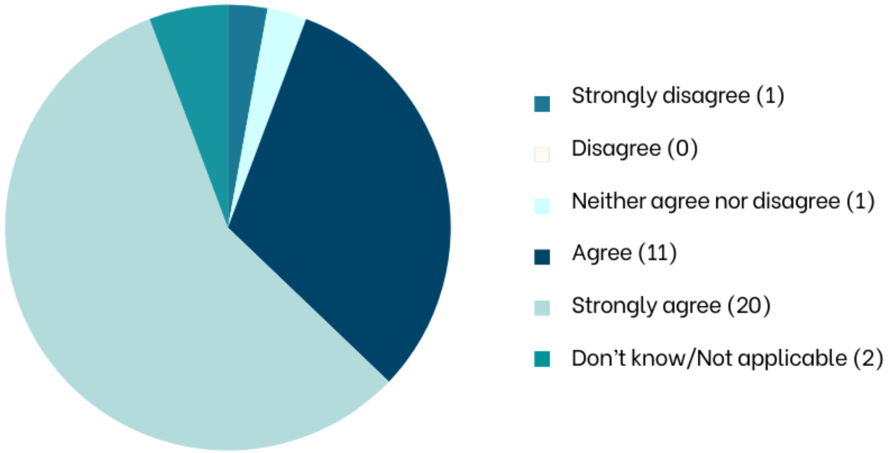


Figure C24 Is Digital Transformation a worthwhile investment?

2.4 Section 3: Impact of the COVID-19 Pandemic

Respondents were asked if the COVID-19 pandemic has resulted in increased use of 3D prototyping technology by their company. Most of the responses reflect that the pandemic has impacted their company's use with (x13) respondents Agreeing and (x10) strongly agreeing. Only (x1) respondent strongly disagreed and (x3) agreed. Only (x5) respondent neither agree nor disagree, and (x3) respondents did not know or it was Not applicable if the pandemic has increased the use of the technology in their company.

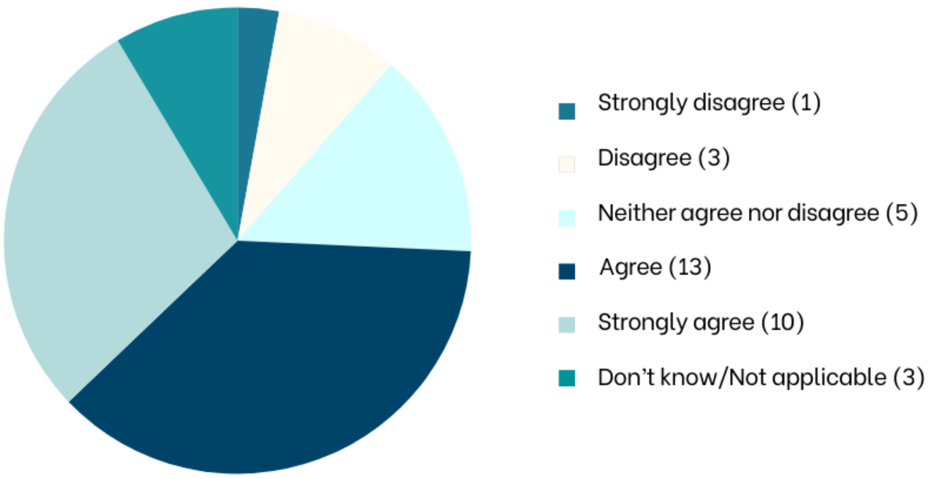


Figure C25 Impact of COVID-19

Respondents were then asked if the COVID-19 pandemic has accelerated their longer-term plans to adopt the use of 3D prototyping technology. Based on the responses, the pandemic has accelerated their longer-term plans to adopt the technology with (x12) respondents agreeing and (x14) respondents strongly agreeing. Only (x1) respondent disagreed and (x3) respondents did not know or was not applicable.

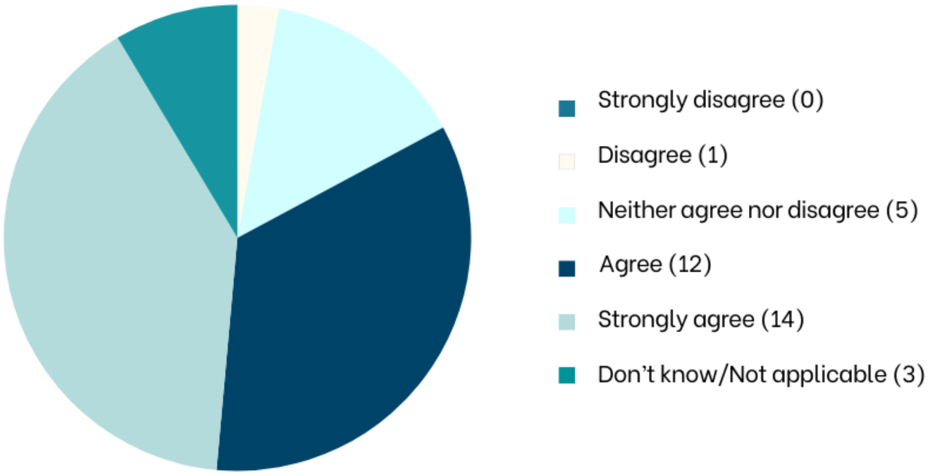


Figure C26 Acceleration of 3D Prototyping Technology Adoption

Data Cleaning

The data has been considered and cleaned. The figures and tables reflect these changes:

Figure 1.2 Roles of Respondents

Other: 1 project manager was added to Manager.

Figure 1.3 Sectors of the Industry

Added 1 to software development (software engineer); 1 fashion design (sports fashion)

Figure 2.7 Use of 3D design technology during product development

Other areas noted were for Trend and Fit evaluation. For this study, trend is considered to be part of Stage *1: Planning and Research.* Fit evaluation is considered part of *Stage 3. Design Development*

Figure 2.15 Training Employees

Two of the other responses were added to Training is provided in-house. However, the other responses were interesting and gave in detail who they hired.

Figure 2.16 Management Software

Three of the 'Other' choices are PLM software: Flex PLM, ENOVIA, and Galaxius. Furthermore, some of the other selections are using a software that manages a variety of product lifecycle management tools. The term New Generation Computing (NGC) Software was given as an option to integrate multiple management tools into one platform. There are other software listed by respondents that are similar to this software solution: Trackvia and Asana. (2) respondents need a new PLM solution.

Software	Description
Asana	a product life cycle management cycle tool for team communication for product management.
ENOVIA	ENOVIA is a Product Data Management (PDM) solution which allows collaboration of data throughout the supply chain. It is essentially a PLM solution.
FlexPLM	PLM system designed for the textile and footwear sectors of the Fashion industry.
Galaxius	Full system able to connect and stream communication across cross functional teams throughout the supply chain.
New Generation Computing (NGC) Software	A platform compatible with integrating Enterprise Resource Planning (ERP) Software, Product Lifecycle Management (PLM) Software, and other product management software all in one.
Trackvia	Product Life Management Software allows organisations to move excel sheets into one platform without having to code. This allows organisations to measure performance, work in real time, increasing productivity and efficiency.

Table C2 Other Management Software Terms

Appendix D: Interview Question Route

Virtualisation of Product Development Process in the Fashion Industry – **Interview** v3 2 FEB 2022

Interviewees

Interviews will be held with:

- Individuals working for companies that are using 3D design software.
- Consultants *(interview questions will be modified slightly for this second group)*.

Interview guide

Interview introduction

Researcher: Thank you for agreeing to be interviewed today. The purpose of this interview is to better understand the use and adoption of technologies within your area of the fashion / garment / textile* industry *(*delete as appropriate).*

Researcher: We've agreed that we're going to record our conversation, to help me with my analysis. Are you still OK with that?

- Prompt response from participant.

Researcher: I'm going to ask a few basic questions to get us started, but I hope we can move into a relaxed conversation about your experiences. I want to remind you that you don't have to answer any of my questions, and we don't have to talk about anything you'd rather not speak about. Is that OK with you?

- Prompt response from participant.

Question route

Section 1: About the Participant

Q1. Firstly, can you tell me a little about your role in your company at present?

Q2. What is your role in relation to 3D design technologies in your company?

- How much of your time is spent using these technologies?
- When did you first begin working with 3D design technologies?
- Do you use 3D design technologies yourself or manage others that do?
- Do you sign off / choose 3D design technologies?

Q3. What is your personal experience of working with 3D design technologies?

- How has this helped you in your current role?
  - *Please can you give me an example?*
- Has it hindered you in your role in any way, do you think?
  - *Please can you give me an example?*

Q4. What types of 3D design technology does your company use?

- 3D body scanners, digital drawing tablets (Wacom), 3D printing, 3D design software, 3D prototyping.

Section 2: About digital transformation

Thank you. Now I'd like to move on to discuss the concept of 'Digital Transformation'. For this study, I am using the term Digital Transformation to mean … the integration of digital technologies within all areas of a business, such as new product or service development, production, marketing, and sales. This may include the use of technologies such as 3D modelling and virtual reality.

Q5. So, do you think digital transformation is a worthwhile investment for companies in the fashion industry like yours?

- Worthwhile = value for money? / Improved competitiveness? / Sustainability?
  - *Can you give some examples?*
- How does this benefit / disadvantage you and your organisation?

Q6. Is your company currently undertaking digital transformation?

If "Yes":

Q6.1 Why has your company decided to currently undertake digital transformation now?

- Is this decision related to the pandemic?
- Is this part of a longer-term strategy?

Q6.2 What are some of the challenges you're facing (in digital transformation)?

- Are you seeing any of the benefits yet?

Q6.3 What will your company look like once digital transformation is completed?

- What do you hope to achieve?
- Where are you in regard to implementation: trial, beginning, middle, near completion.

If "No":

Q6.4 What factors do you think might result in your company deciding to undertake digital transformation?

- Competitors actions in this direction?
- Is this decision related to other factors: environmental and business sustainability, COVID-19, longer term business strategies?

Thank you. Now I'd like to move on to discuss the current state of the Fashion Industry. Digital technologies are considered by experts a solution for key issues our industry is facing such as environmental and business sustainability, supply chain fragmentation, authenticity, and craft. So, this leads me to the next question:

Section 3: About virtualisation

Thank you. Now, I'd like to move on to discuss the concept of 'Virtualisation'. For this study, I am using this term 'virtualisation' to mean the process of creating a 'virtual' (i.e. 3D computer-based) model of a physical object. And how this virtual model is used throughout the product development process and beyond — for example in marketing, retail, and so on.

Q7. Can I ask, what is your view on Virtualisation of the whole product development process?

Q8. So, do you think virtualisation is a worthwhile investment for companies in the fashion industry like yours?

- Worthwhile = value for money? / Improved competitiveness? / Sustainability?
  - *Can you give some examples?*
- How does this benefit / disadvantage you and your organisation?

Q9. To what extent do you think virtualisation has the potential to solve key issues facing our industry — or create new issues? (Sustainability, fragmented supply chains, transparency, authenticity, innovation, craft, etc)

Section 4: About authenticity and craft [Group 1: Consultants/ Managers and directs]

Q10. What issues do you think virtualisation might raise for designers?

- What about concepts of 'craft' or 'authenticity'?

NOTE: These questions will be supplemented by questions relating to issues / factors raised by survey responses

Section 4: About design [Group 2: Designers]

Thank you. Now I'd like to move on to discuss the impact of digitalisation and the adoption of new technologies on the role of the designer in the fashion industry.

Q10. Does 3D design software inspire you as a designer? Why or why not?

- Can you give me an example?

Q11. To what extent do you feel motivated to learn 3D design tools?

- Why or why not?

Q11.1 Does your company / employer support you to learn or improve your skills with 3D design software?

Q12. How do you think 3D design technology impacts your workflow when doing your daily tasks?

- Can you give me an example.

Q13. How do you think 3D prototypes impact communication across functional teams in your organisation

- E.g. between, merchandisers, designers, manufacturers, etc.
- Can you give me an example?

Q14. How do you think 3D design technologies are impacting your role as a designer?

- In terms of fashion design being traditionally seen as a 'craft', or the perceived 'authenticity' of your products by consumers?
- How does technology and virtualisation challenge or support the role of the designer, do you think?

Interview ending

Researcher: Thank you for being interviewed today. I will be writing up the results for my PhD thesis and would be happy to share the findings with you— if you would be interested in receiving these.

Appendices E: Interview Participants' Job Roles

Interview Participants' Job Role – Consultants/ Managers and Directors (x15)			
Job Title	**Participant CODE**	**Sector Type**	**Job Description**
Head of Growth	CMD01	Brand and Manufacturing Consultancy	Marketing and optimising opportunity generation, meaning looking into how the market is evolving, how they benefit from company services, understanding their challenges to overcome barriers towards digital efforts, building pricing and monetization engines. Role in relation to 3D design technologies: Part of the marketing team to grow the organisation. Therefore 1) observing how the marketing is evolving and reacting to it through the services provided by the company. Becoming experts. 2) scaling digital transformation within organisations.
Managing Director of European Subsidiary	CMD02	Garment Manufacturing	Specialised in sock and seamless sportswear apparel. Role in relation to 3D design technologies is limited but responsible for design and R&D in Europe and the US with existing and new customers. Also explore the appropriate use of 3D technology in our context.
Digital Entrepreneur within Innovation Team	CMD03	Garment Manufacturing	Includes: explore up and coming technologies facing the industry, test and incubate the technology, roll it out, explore DPC as head of DPC, plan for disrupting technologies, build partnerships, etc,
Head of soft goods engineering	CMD04	Hard Product Manufacturer and Brand	Current role in relation to 3D design technologies includes responsible for 2D pattern developments, integrating 3D design software.
Chief Executive Officer (CEO) and Cofounder	CMD05	Digitising Textiles/ Suppliers	Main role is project management over the company. Other responsibilities: conduct research, manage finances, support clients with digitisation of fabrics.
Chief technology officer and cofounder	CMD06	Digitising Textiles/ Suppliers	Role includes a variety of responsibilities including carrying out research and development of designing a system to capture digital imaging of fabric. This requires practical thinking around specific cameras to achieve desired outcome, and how this impacts the design of the system. This leads to the development of software. Building customer engagement through discussions around the technology. Ensures there's interoperability with other software and technology with the company's own systems.

Chief Growth Officer	CMD07	Technology Vendor: Digitising Textiles/ Suppliers	Main role: combining an extensive background of knowledge and experience of textile and apparel supply chain knowledge, marketing, and communication. Other responsibilities: sales and revenue growth, business development, marketing, communication, recruiting new clients, support clients with implementation of technology. In discussion around what CGO means he highlights there are multiple areas such beyond monetary gains. encompasses the customer journey, therefore how companies can market with Bandicoot, part sales, listening and having conversation with industry for R&D.
Head of the Quality and Technical team	CMD08	Fashion Brand/ Retailer	Role is to ensure quality of product, manage QA team, and all processes in regards to product development– working with design team to create shapes and the sizing and fit, maintain garment blocks, keep up to date with global body measurements, conduct surveys every 6–8 years on current consumers who are changing and new target customers and their body shape, maintain fabric approvals such as quality from the factories, monitor compliance of the factories to ensure international safety standards and/or chemical compliance.
General Manager	CMD09	Consultancy	Role: working directly with teams within brands and retailers in the West. Other responsibilities: carry out business development, project management, analyse the client's design, development, and selling process, and figure out where 3D will benefit them and help execute the project.
Product development manager	CMD010	Garment Manufacturing	Overseeing a number of different products across men's, women's, kids, and swimwear. Other responsibilities include everything from initial product development from concept right through to creating tech packs before design is sent for physical prototyping.
Head of Marketing	CMD011	Software Vendor– 3D fashion design software	Main role is to communicate the capabilities of the technology to potential clients. Other responsibilities: explaining the advantages of the technology, how to use the technology, how to implement the technology in a brand's design and development process and utilisation for marketing strategies.
CEO and Founder	CMD012	Consultancy and Magazine Publisher	Role consists of advising around technology for the fashion industry. Other responsibilities include research and creating educational content for the brands/retailers and a variety of sectors within the fashion industry.
Senior Lecturer in Fashion Technology	CMD013	Higher Education: focus on pattern engineering	Teaching, supporting PhD researchers, conducting research, main focus pushing research on embedding body scanning of patterns in product development. Managed fashion design software Lectra Modaris contract. Explore other digital 3D modelling software. Exploring open-source platforms
Brand Operations Manager	CMD014	Brand Management Agency	Marketing, PR events, photoshoots, management, and social media management for both companies.

President of Company	CMD015	Technology Vendor and Consultancy specialising in textiles and colour.	Leads and supports the business operations. Consulting for apparel brands around digital product development process and textile mills for colour matching and management process. Company has developed own fabric digitiser to support digitalisation for the industry.

Table E1 Defining Jobs– Group 1 Consultants/ Managers and Directors (x15)

Interview Participants' Job Role – Designers (x15)			
Job Title	**Participant CODE**	**Sector Type**	**Job Description**
Director of Design technology	DP01	Garment Manufacturer	Tech design, leading tech design and patterns, and our 3D teams. In relation to 3D design technologies: Prior experience of 3D implementation. Responsible for bringing 3D to the organisation.
3D Apparel Specialist– Tech and Support Team	DP02	Software Vendor– 3D design software	Teach and support clients with fashion design software tools and training to skill up their teams. Support clients with challenges they face with implementation of the software and software tools. In regard to 3D design technologies: Job Role is centred around 3D as discussed in the job role.
Senior Designer at as a supplier/ manufacturer	DP03	Garment Manufacturer	Oversees accounts on jersey, nightwear and lingerie, utilising 3D fashion design software. In regard to 3D design technologies: utilities 3D design software to carry out daily tasks and responsibilities in relation to product development.
Digital Product Creator	DP04	Garment Manufacturer	building digital assets for digital garments and wholesale accounts, works alongside the design team to convert designs into tech packs, make the 3D version using BW, exploring AR, VR, and avatars (early stages). In regard to 3D design technologies: Job Role is centred around 3D as discussed in the job role.
Patternmaker/ Super User	DP05	Fashion brand/ retailer	Uses CLO and trains employees in CLO, helps with the implementation of the software across patternmaking, designers, and print designers. Works with concept teams and managers to understand what it takes to lead a 3D design digital team. Also involved with a variety of projects throughout the company.
3D Fashion Designer	DP06	Fashion brand/ retailer	Part of the company's team that's responsible for implementing 3D design software. Training colleagues, preparing styles in the form of digital patterns to be used during DPC, creating 3D digital styles for digital showrooms.

3D technical designer	DP07	Garment Manufacturer	Responsibilities include traditional responsibilities of a technical designer with the addition of 3D fashion design skills. Furthermore, carry out implementation within the traditional workflow. An example would be to carry out fittings. Main responsibility around 3D is to create a company block library which includes the standard fit blocks, repeat style blocks, trimmings.
Garment Technologist	DP08	Garment Manufacturer	Undergoing project updating range plans, design, and fit. Part of the entire product development process: alterations to size charts and patterns, construction files, tech packs. Role does not involve 3D. The role requires the use of 2D design with vector graphics software and a separate software for patterns.
Junior Designer/ Super user	DP09	Fashion Brand/ Retailer	super user requires creating process in workflow, teach colleagues, manage team members
Central 3D Visualisation Artist	DP010	Garment Manufacturer	"Central 3D artist" responsible for: supporting all 3D artists and users, recruiting new talent, train and support new talent, follow of updating knowledge on new features, explore new technologies, explore new uses of technologies, create new workflows, simplify workflows, solve issues that arise, speed up workflows, communicate with 3D vendors on the company needs. Involved in the DPC process, creates samples in 3D, trains new employees and support them, as well as works in R&D, onboards 3D artists, stay up to date with software updates and inform others, keep them engaged with the 3D, develop 3D workflows which speed up the traditional process, communicate to vendors and provide feedback and needed requirements or support.
Business development manager for education	DP011	Software Vendor– 3D fashion design software	Engaging with education institutions, mainly higher education, help them implement the software, help develop/plan/create their curriculum and templates, help students gain access to the software.
Tech designer– Knitwear: tops	DP012	Garment Manufacturer	build and maintain tech packs, create 3D illustrations for all knit tops. The role requires the use of 3D design prototyping technology for the creation of some 3D tech packs and 3D images for development and bids.
Creative Director	DP013	Garment Manufacturer	Partner/owner and active in running the company. Responsible for the creative aspect of the business such as designing, pattern making. Also is involved with the communication with clients and planning, buying, and sourcing material. However, more focused on production for both digital design output and the management of the physical factory production.

			Utilises 3D design software [Company B] for all product development processes for example pattern work and designing.
3D Design Specialist	DP014	Software Vendor– 3D fashion design software	3D design specialist focusing on presales within the marketing department. The role consists of two main functions: 1) To create content through designing digital garments to present to clients the capabilities of software. The digital assets are used in promotional content. 2) To build an extensive digital block library of garments (initial pattern outline of a garment) for clients. Works with graphic designers, designers mainly focused on rendering and animation software, writer/editor. In regard to 3D design technologies: Creating digital twin models to build up digital asset libraries for brands.
Senior Technical Developer	DP015	Fashion Brand/ Retailer	Responsible for the menswear Performance side of the business of product and technical development, technical development. Fashion focused, but work comes from a performance and outdoor wear background. Different roles require different focuses around 3D.

Table E2 Defining Job roles– Group 2 Designers (x15)

Breakdown of Countries by Participant			
Group 1: Consultants/ Managers and Directors (x15)	**Number of participants**	**Group 2: Designers (x15)**	**Number of participants**
United Kingdom	4	United States	6
United States	2	Sweden	3
Australia	2	The Netherlands	2
The Netherlands	2	United Kingdom	2
Germany	1	Canada	1
Sri Lanka	1	Sri Lanka	1
Singapore	1		
China	1		
Denmark	1		

Table E3 Breakdown of Countries by Participant

Appendix F: Case Study 1

Role	Main Responsibilities
CEO (x2)	Manage and maintain business operations. Set clear goals and initiatives for the success of the business.
Design Team (x2)	Conduct design/trend research using social media and trend forecasting website. Responsible for tech pack development and maintenance of changes between patternmaking team, sales, and design team. The team creates the virtual assets.
Design Team Lead (x1)	Responsible for a variety of tasks throughout the different teams such as: • Manages design team and ensures tasks related to design are carried out. • Works with 3D design software and develops 3D virtual prototypes. • Main contact between the design team and patternmaking team. • Works closely with upper management in decision making. • Works on special projects such as Company 1's internal brand.
Patternmaking/ Technical Team (x2)	Responsible for the initial creation of garment patterns for sampling in 3D design software, which includes: • Make alterations to digital pattern files and update the 3D digital prototype. • 3D files are converted to 2D in preparation to print for physical patterns. • Prepare instructions to assemble garments for the production team. • Communicates with the production team directly.
Sales Team (x2)	Creates pricing strategy and carries out sales meetings. Other responsibilities: • Create the bill of materials (BOM). • Onboards clients and assesses if the company's solutions are appropriate. • Supports long-standing and new clients through the production process. • Educates clients of Company 1's workflow with 3D digital prototypes.
Buying Team (x1)	Responsible for the procurement of materials in the BOM provided by the Sales Team. Other responsibilities: • Ensure traceability by documenting materials to ensure certifications are met of materials such as yarn, fabric, trims/labels, dyeing, and final products. • Maintaining and organising each client folder with source codes.
Systems Architect (x1)	The role emerged from the need for support beyond what the traditional IT role can provide. Traditional IT focuses on problem-solving solutions for existing systems, but not on developing new solutions. The participant creates simplified integrated or innovative solutions and configures the products and assets necessary for streamlined and efficient systems.
Business Developer (x1)	The role specifically focuses on environmental impact by researching and staying up to date with legislative developments with and protocols. This includes collecting, documenting, and mapping Company 1's carbon footprint. Moreover, administers Company 1's SharePoint system, which holds the CO_2 accounts for all stakeholders.
Founder and Brand Director (x1)	Founder and brand director of Company 1's internal brand. Responsibilities include managing all operations required for the success of the brand.

Table F1 Company 1– Roles and Main Responsibilities

Appendix G: Case Study 2

Role	Main Responsibilities
Founder and Creative Director	Founder responsible for managing all creative aspects of the company including conducting design, research, and production techniques (Company Website, 2022).
Founder and Business Director	Founder responsible for managing all business operations of the company including customer facing responsibilities, project management, purchasing, etc. (Company Website, 2022).
Lead Garment Technician	Lead garment technician responsible for assisting both Creative and Business Director. Other responsibilities include: • Manages all digital activities within digital product creation– i.e. create and manage digital pattern files, digitising fabrics. • Carries out traditional pattern making processes including pattern grading, tech pack creation, garment measurements, etc. • Conducts training/ tutorials in digitising fabrics and other digital skills. • Trials new software programs and technology • Participates in the decision-making process of selecting technology.
Digital Fabric/Open-Source Intern	Intern responsible for focusing on developing Company 2's open-source platform. Responsibilities include: • Adjusting digital pattern files to ensure details and grading is correct for clients. • Updating open-source guide documents • Updating open-source patterns from contributors • Developing Digital Fabric Library • Assuring quality of visuals of garment and collections. • Creating 3D digital visuals and animations • Assuring trims for garments are correct • Setting up initial steps for product development
Purchasing Coordinator	Purchasing coordinator responsible for assisting the business director with all purchasing and buying required for each project. Other responsibilities include coordinating clients, new projects, all administrative, and business operations.

Table G2 Company 2– Roles and Main Responsibilities

Services Offered (Company 2's Website, 2022)	
• Design and innovation consultancy • Kinetic Garment Construction consultancy • Product development utilising 3D visualisation in CLO3D	• Rapid digital and physical prototyping • Small series production • Made to measure production • Mass-customisation production

• Digital interactions as online fitting etc. • Pattern making, grading and marker making	• Local network of manufacturers (prints, embroidery, CNC cutting, fabrics etc) together with a global network of suppliers

Table G3 Services

Hardware–approx. 30 different industrial machines (Company 2's Website, 2022).		
• One-needle lockstitch machines, together with pipes for bias bindings • 3-, 4- and 5-thread overlock machines • Merrow active seam overlock • Flatlock machine • Interlock machines • Button sewing machine • Metal button attaching machine	• Machine for creating fabric covered buttons • Buttonhole machines for shirt (straight) and round holes. • Buttonhole machines for jeans and tailoring (eyelet) holes. • Bartack machine • 3 needle Feed-of-the-arm fell-seam machine • Waistband machine • Blind stitch machine	• Chainstitch machine • Zig-zag machine • AMF Pick-stitch machine • 2-needle machines • Various cutting machines • Continuous fusing press • Heat transfer press • Pattern plotter 90cm and 180cm • Printer for care labels

Table G4 Hardware

Appendix H: Case Study 3

Company 3 Role	Main Responsibilities
Division President	Responsible for all aspects of the performance of the company: bottom line, Earnings Before Interest, Taxes, Depreciation, and Amortisation (EBITDA), profitability, cash flow, etc.
SVP Commercial Strategy	Responsible for reviewing market research and focusing on further growth and development, setting strategic objectives, and managing the risks of the company.
Product Design Manager	Works alongside the product design team and with cross functional teams in a variety of offices. Assists with managing production in China and with the design team in the Hong Kong office, marketing operations, and designing fabric collections. Other responsibilities include present product, assist customers with questions and information about the product, and design for designated client.
Sr. Merchandising & Product Design	**Senior Design Role:** Creates seasonal lines of trends to be presented to brands. Other responsibilities: ensuring presentations include all the information customers would want and interpret what they may want (i.e. the final garment, headers, legs, etc.), and assists and manages the design process. **Merchandising Role** Responsible for merchandising within the Mexico plants. Responsible for knowing what goes into a product, how much it costs, yarn shade, all different fibres and components, technologies and finishes, and everything else that makes up a denim. Other responsibilities include: • handle pricing strategy for customers, participate in the decision-making process with finance, accounting, the Division President • sales team to support monetary initiatives, works with inventory team to conceptualise production, managing cash flow, working capital.
Product Design Assistant	Responsible for sample garments. Therefore, tracking orders and new styles approved by the team. Other responsibilities include photographing garments and denim samples for product profiles and assisting senior merchandising and product designers.
Account Manager (x3)	Greensboro Sales Contact for designated brand. Main responsibilities include meeting assigned accounts needs, carrying out sales presentations of fabric, etc.
Sales Support	Main support for the sales team. Provide sales tools to assist selling such as: preparing sample garments, fabric swatches and headers. Other responsibilities include: create processes for new projects and update old processes, maintain, and organise documents for future use, prepare PowerPoint presentations, maintain and create product profile documents

	in InDesign, support planning of trade shows, ship samples and other materials needed to clients as well as colleagues.
European Sales	Sales manager for all of Europe apart from Scandinavia. Main responsibilities: meet customers' needs, offer customer support, recruit new customers, and travel to meet clients.
Marketing Manager	Marketing Manager for all brands under the parent company. Spearheaded project in exploring digital transformation.
Marketing Lead	Works alongside the Director of Marketing to rebrand and create brand awareness through promotional content for all 15 brands under the parent company. Other responsibilities include: updating visuals, taking photos of products, carrying out video editing, creating social media content through "storytelling", managing all 15 social media accounts, assisting with graphics for digital ads/email marketing/ or printed material, etc.
Technology Vendor– Digital Fabric Scanning Solutions	Virtual fabric scanning solution focusing on capturing the true to life visualisation of fabrics.

Table H1 Company 3– Roles and Main Responsibilities

Appendix I: Digital Product Creation Pathway

Three types of business models of selling garments in establishing goals for approaching DPC (see below Table 10.1). Depending on the business model of the company, the solutions, workflow, and processes are different. See pathway below (Participant CS1010, 2022).

5 different categories of products:

- **Fast fashion category**: short runs of styles, quick turnaround within a few weeks, and designed cheaply.
- **Collection category:** designed with a theme. It takes the process around 6–12 months in advance. The collection is only sold once.
- **"The Gap" category:** Trends or missed gaps of styles that need to be added in assortment. It takes around 1–3 months.
- **The Replenishment category:** basic goods which are created every season.
- **Technical Wear/ Workwear category:** utilitarian wear based on functionality. Every product is created with certain standards, and it often doesn't require new styles.

A. Selling Garments Digitally	1. Business to Consumer (B2C)– sell directly to consumers using digital garments.
	2. Business to Business (B2B)– Invite clients to physical showroom and present garments digitally.
	3. Virtual Showroom– purely virtual space to present and sell digitally. Participant CS1010 discusses it is too early to know what consumers want when choosing a virtual or physical shopping experience, and suggests it might be a mix and match between the virtual and physical. Nevertheless, it is important to know how to create solutions for companies and their digital product creation journey.
B. Storing Garments	1. Warehouse Stock
	2. Retailer– Physical shop to sell direct to consumer.
	3. Ecommerce/ Metaverse– Both digital selling; however, both require digital workflows.
C. Digital File Types	1. A Native– true to life model or a digital twin.
	2. Scanned file– scanned in 360-degree view of garment. Still enables to visualise the garment, but not true to life. This scanned image of garments is prepared for PowerPoint slides or presentations.

Table I 1 Digital Product Creation Path

Appendix J: Ethics Application

APPLICATION DETAILS

Project Title
Future Fashion Industry: The Effects of Virtualisation of the Product Development Process

Project Type – *this is a drop-down box with options from which you select the best description for your research.*

- PG Research

Project Description: (in layman's terms) including the aim(s) and objectives and justification of the project (max 300 words)
The fashion industry is facing a series of challenges and issues with traditional production and business practices. Due to social, economic, environmental, and cultural changes, the fashion industry is undergoing a transformation. Virtualisation in the design, manufacture, and sales is changing the way fashion business is carried out. Virtualisation is simulating processes virtually to scale workloads and increase productivity. 3D design software creates simulated prototypes that communicate accurate representations of garments, cutting out millions of physical samples and resources. 3D assets are used to display physical products on e-commerce websites. Due to the COVID-19 pandemic, traditional ways of presentation, such as fashion catwalk shows, are moving towards virtual showrooms and digital samples as the main communication tool to buyers and manufacturers. These changes are important to understand because they create new ways of doing business, have the potential to support environmental and sustainability efforts, and introduce new forms of visual communication for selling and promotion. This doctoral research addresses the question: How is virtualisation of the product development process impacting the fashion industry? There are currently few academic studies looking in depth at this in relation to the fashion industry, and few on the changes since Covid-19. The objectives of this project are: (i) to understand how virtualisation of the product development process is impacting the fashion industry; (ii) understand the process by which companies are undertaking the virtualisation process; (iii) identify the technologies that are enabling virtualisation of the product development process; and (iv) explore concepts of 'craft' and 'authenticity' in the virtualisation of the design and product development process.

Proposed Start Date:

01/02/2021

School of:

School of Arts, Media & Creative Technology

The project involves the following types of activity (Select all that apply)

- Human Participants
- Data

Will the activity involve any external organisation for which separate and specific approval is required?

No

Will the activity require National Research Ethics Service (NRES) approval?

No

Will your research be a Clinical Trial of an Investigation Medicinal Product (CTIMP). Please refer to the NRES algorithm.

No

Will your research involve research participants identified because of their status as relatives or carers of past or present users of these services (adult and children's healthcare within the NHS and adult social care)?

No

Will your research involve collection of human tissue or information from any users of these services (adult and children's healthcare within the NHS and adult social care)? This may include users who have died within the last 100 years.

No

Will your research involve the use of previously collected tissue or information from which the research team could identify individual past or present users of these services (adult and children's healthcare within the NHS and adult social care), either directly from that tissue or information, or from its combination with other tissue or information likely to come into their possession?

No

Will your study involve research participants identified from, or because of, their past or present use of services (adult and children's healthcare within the NHS and adult social care), for which the UK health departments are responsible (including services provided under contract with the private or voluntary sectors), including participants recruited through these services as healthy controls?

No

How is it intended the results of the project will be reported and disseminated? (Select all that apply)

Dissertation/ Thesis
Academic papers / publications
Presentations at academic conferences

2. THE NATURE OF THE PROJECT IS DESCRIBED AS:
Please describe the nature of your research. Select all that apply. Based on your selections you may be required to attach associated documents.

Behavioural observation, Survey(s) Interview(s) Qualitative methodologies (e.g. focus groups) A survey will be conducted with research participants—see uploaded document. Interviews will also be conducted, that will explore in more detail the themes from the survey:

- Behavioural observation

- **Survey(s)** – *please upload a copy of the Survey / survey*
- **Interview(s)** – *please upload a list of questions to be asked or, if semi-structured, the topics*
- **Qualitative methodologies** (e.g. focus groups)

RESEARCH METHODOLOGY (Please be specific)
The project will undertake empirical research that addresses the four research objectives, as follows: 1. How might we identify the technologies that are enabling virtualization of the product development process? Survey Method: • Identify technologies that are enabling virtualization – in the form of a list and the parts in the process, where used. • Identify companies (100+) that are identified as using 3D design software (found on websites of 3D software companies, trade press, etc.) • Administer a Survey to companies about their use of 3D software. 2. How might we understand the process by which companies are undertaking the virtualisation process? Interview Method: • Conduct interviews with consultants supporting 3D design software (x15). • Conduct interviews with those working for companies using 3D design software (x15). 3. How might we understand how virtualizing the product development process is impacting the fashion industry? Case studies using a range of methods (including observation, interviews and focus groups). • Identify potential case studies of fashion design companies and conduct 1-3 case studies using mixed methods. 4. How might we explore concepts of 'craft' and 'authenticity' in the virtualization of the design and product development process? • Identify from the literature concepts of 'craft' and 'authenticity' • Observation of designers and their working context (e.g. workspace, studios, etc) • Content analyse data from the interviews undertaken in 2 and 3 above.

3. HUMAN PARTICIPANTS

Does the activity involve Human Participants?	YES
Answering YES will prompt the following additional questions:	

Will the participants be from any of the following groups (select all that apply):

Students or staff of this University	Those with learning disability
Children/legal minors (anyone under the age of 18 years)	Those who are unconscious, severely ill, or have a terminal illness
Patients or clients of professionals	Those in emergency situations
Those with dementia	Those without mental capacity
Those with mental illness (particularly if detained under the Mental Health Act)	Any other person whose capacity to consent may be compromised
Prisoners	Adults who are unable to consent for themselves
Young Offenders	Other vulnerable groups
A member of an organisation where another individual may also need to give consent	Those who could be considered to have a particularly dependent relationship with the investigator, e.g. those in care homes

Please justify their inclusion and your sampling.

Proposed participants will be fashion industry professionals from across the supply chain. The study will involve garment industry professionals, including: company executives; directors; consultants to the garment industry; fashion designers; technical designers; 3D artists; print designers; and textile designers. The study will also involve relevant fashion retail sector professionals, including: fashion buyers; merchandisers. Finally, the study will involve professionals from the technology sector enabling virtualisation, including technology developers and vendors; software developers and vendors; and technology research and development professionals.

Will your research involve a Clinical Trial?
No

Do you intend to register your trial on a clinical trial database?	NO

Where do you intend to register your clinical trial?
N/A

Have you undertaken the Safeguarding and Prevent training relevant to your project?	N/A

Is a Disclosure and Barring Service (DBS) check required?	N/A
Please advise status of DBS clearance (e.g. gained; in process; etc)	N/A

Please indicate exactly how participants in the study will be (i) identified, (ii) approached and (iii) recruited.
Identified: Garment industry professionals, fashion retail sector professionals and technology sector professionals will be identified as follows: Key industry bodies and associations will be identified from the academic and trade literatures. For example, British Fashion Council; Fashion Designers of America, etc. These will be approached to disseminate invitations to their members to participate in the survey. The survey will include a question allowing participants to opt into a potential follow-up interview. From analysis of the survey results, potential interview candidates will be identified. Potential interview candidates will also be identified from the academic and trade literatures. **Approached:** ***Survey participants –*** Plan to reach participants through LinkedIn and Fashion organisations such as The British Fashion Council and Council of Fashion Designers of America in a potential newsletter. Survey participants will be asked at the end of the online survey if they would be willing to participate in a follow-up interview, and if so, will be asked to provide their contact details (email address). ***Interview and focus group participants –*** Survey participants indicating their willingness to participate in interviews / focus groups would be contacted via email. Contacts gained through previous networking (e.g. attendance at events; online communications; etc.) or who have contacted the researcher due to their interest in the research area, will be approached by email to participate in the research. **Recruited:** Participants signalling their willingness to take part in the research will be sent the *Project Information Sheet* and the *Informed Consent Form*, which they will be asked to complete and return prior to commencement of the interview / focus group.

Will consent be sought? YES / NO	Yes

If you answer NO, then you must provide a detailed explanation as to why consent will not be sought.	

Please explain how consent will be obtained
Informed consent will be obtained using the *Project Information Sheet* and the *Informed Consent Form* provided to participants (see attached).

How long will the participants have to decide whether to take part in the research?
We estimate that participants will receive the Project Information 7-14 days before the interview or focus group is scheduled, and any questions will be answered prior to consent being provided and research commencing.

What mechanism is there for participants to withdraw from the project, at what interval(s) and how is this communicated to the participants?
Participants can withdraw for the study at any point, as outlined in the Informed Consent Form (see attached). Participants with any concerns can contact the researcher, research supervisors or the University of Salford Data Protection Officer (DPO).

What arrangements have been made for participants who might not adequately understand verbal explanations or written information, or who have special communication needs?
N/A

Do you propose to pay or reward participants?
N/A

Does your project involve the potential imbalance of power/authority/status, particularly those which might compromise a participant giving informed consent? Explain how this will be mitigated.
No

Will deception of the participant be necessary during the project?
No.

Does the activity involve any information pertaining to illegal activities or materials or the disclosure thereof?
No

Does the project involve any possible distress, discomfort, or harm (or offence) to participants or researchers? (including physical, social, emotional, psychological and/or aims to shock / offend – e.g. Art)
No

What are the potential benefits of the research?
Educational purposes only. The creation of knowledge and understanding for the apparel industry of high technologies and advantages and disadvantages of virtualisation of the product development process to sustain future industry development. This is likely to be of interest to participants from the fashion / garment industry.

Will you provide Debriefing, Support and/or Feedback to participants?

No

4. **RISK OF HARM AND RELATED ISSUES**

Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?	NO
Answering YES will prompt the following additional questions:	

Please explain any risk of physical or psychological harm distress or discomfort
N/A

Are drugs, placebos, or other substances (e.g. food substances, vitamins) to be administered to study participants?	
Please describe the use of drugs, placebos, or other substances.	

Is the substance/food approved by the Medicines & Healthcare Products Agency and/or Food Standards Agency (i.e. available over the counter)?	
ii. Does the substance/food contain any known allergens	N/A

Is there any possible psychological risk to the researcher? Please describe possible psychological risk to the researcher.
No

Does the activity involve high levels of risks to the researcher? *(e.g. lone working at night; interviewing in your own or participants homes; observation in potentially volatile or sensitive situations).* Please explain the high level of risk to the researcher
No

Will participants undergo sound exposure beyond the Lower Action Level of the Physical Agents (noise) Directive?	
Please describe any sound exposure	

Does the activity require the use of hazardous substances?	**No**
Please detail any use of hazardous substances	
N/A	

Is the use of radiation (if applicable) over and above what would normally be expected (for example) in diagnostic imaging or radiotherapy?	
Please detail any use of radiation	
N/A	

Are there likely to be culturally sensitive issues/topics (e.g. age, gender & ethnicity)?	**No**
Please detail any reference to culturally sensitive issues / topics	
N/A	

Will the research and outcome involve nudity or sexually explicit material?	**No**
Please justify involvement of nudity or sexually explicit material	

5. COLLECTION AND USE OF DATA

The research involves collecting data about human participants?	

The research only involves analysis of already collected data, which exists in anonymous form, and for which participants have already given consent that it can be used in future research?	
Answering NO will prompt the following additional question:	

Please provide details of the storage and protection of your physical / electronic data.
Personal password protected drive.

Will the project be using prospectively collected data that is anonymous to the researcher?	No

Will the project involve access to confidential information about people without their consent?
NO

Will the project involve non-anonymisation of participants (i.e. researchers may or will know the identity of participants and be able to return responses)?	

Do participants have the consented option of being identified in any publication arising from the research?	

Will the project involve the use of personal data (*i.e. anything that may identify them – e.g. institutional role – see Data Protection checklist for further guidance*)?	

6. TISSUE, FLUIDS, DNA

Does the activity involve tissues / fluids / DNA samples?	
Answering YES will prompt the following additional questions:	
Does the activity involve work with human tissue/body fluids?	

7. EXCAVATION AND STUDY OF HUMAN REMAINS

Does the project involve excavation and study of human remains? Please give details.	
If you answer No to this question you can proceed to the next section	

8. OTHER ETHICAL CONCERN

Are there any other potential ethical or political concerns? e.g. Are you aware of any potential ethical concerns or political concerns that may arise from either the conduct or dissemination of this activity, e.g. unethical practices of companies funding this research; results of research being used for political gain by others; potential for liability to the University from your research? **Please describe any additional ethical or political concerns.**
Do you have any ethical concerns about collaborator company / organisation, e.g. its product has a harmful effect on humans, animals, or the environment; it has a record of supporting repressive regimes; does it have ethical practices for its workers and for the safe disposal of products? Please outline any ethical concerns about collaborator company / organisations.

Appendix K: About the author

About the author

After completing my *BSc in Textiles, Merchandising, and Design* with a minor in Entrepreneurship at Middle Tennessee State University, I came to the University of Salford to pursue a BA (Hons) in Fashion Design. During this program, I created a final collection, which deepened my understanding and appreciation of the fashion design and product development process. Presenting my final collection at London Graduate Fashion Week was a pivotal moment. Immediately afterward, I travelled to Shanghai with nine other students from various UK universities for a three-month fashion design project and summer training programme with The China Academy of Art at the Shanghai Institute of Design. This cultural experience allowed me to explore my heritage as well as observe first-hand the high pace fashion industry in East Asia.

Upon returning from Shanghai, I continued with education by pursuing a MA Design for Communications course at Salford. I developed my practice as a 3D digital fashion designer with a focus on fashion sustainability. I spent the year creating my final body of work using CLO Virtual Fashion software and exploring practical applications of my studies as I considered my career path in the fashion industry.

PhD study

After completing my MA Fall 2019, I was offered funding and the opportunity to pursue a PhD to explore my subject further. Through my studies and experiences, I have developed a true passion for 3D digital fashion design, as well as a commitment to contributing to the transformation of the fashion industry as both a practitioner and academic. The transformation represents an opportunity to innovate and revolutionise fashion business practices. In addition, utilising virtual technologies can provide solutions to reduce environmental impact, to create equality for all stakeholders, and promote economic growth.

My PhD has allowed me to actively participate in the industry. I was invited as a guest panellist to speak on behalf of Browzwear at PI Apparel Amsterdam 2022, discussing creativity and collaboration on the topic of: "How 3D Empowers Designers to Unlock Their Creativity with Sustainability in Mind". I was also invited as a guest lecturer by the Suzhou Business School to speak on the topic of: “The Environmental Impact of Our Clothes and Sustainable Fashion Future.” My research methodology has enabled me to conduct research in Denmark, Sweden, and the United States. The experiences have led to a deeper understanding and had a profound personal impact. Through this PhD, I hope to contribute to this growing area of research and support improved understanding of the transformation the fashion and apparel/ garment industry is undergoing.

Lecturing Fashion Business & Promotion and 3D Digital Fashion Design

Alongside my PhD study, I taught two years at the University of Salford across undergraduate and postgraduate levels. During the COVID-19 pandemic, I adapted my teaching to meet the ever-changing needs of students and the university. I performed module leader duties on “The Customer Journey” and “Fashion Marketing and Ethical Practice” modules of the BA (Hons) Fashion Business and Promotion. I worked independently to develop contemporary module materials, deliver lectures, and develop and mark assessments to meet team objectives. Moreover, I supported BA (Hons) and MA Fashion Design students with developing their portfolios and concepts for final major projects by challenging ideas, fostering debate, and encouraging creative and rational thinking. I introduced these cohorts of students to 3D design software Browzwear and digital fabric scanning solutions, inspiring them to develop their interests and pursue careers in digital fashion design. I have joined Manchester Fashion Institute (MFI) at The Manchester Metropolitan University as a Digital Fashion Design and Innovation tutor. In this role, I train the next generation of 3D digital fashion design practitioners in digital fashion theory, 3D design software, fabric digitalisation, and contemporary industry practices. After completing my PhD, I hope to continue developing my research and bridging the gap between academia and industry.

References

Abdulla, H. (2022 December 2). How prepared are brands for the incoming EU green claims proposal? Just-style. Accessed 24 November 2023. Retrieved https://www.just-style.com/features/how-prepared-are-brands-for-the-incoming-eu-green-claims-proposal/?cf-view

Abernathy, F.H., Dunlop, J.T., Hammond, J.H., & Weil, D. (1999). *A stitch in time: lean retailing and the transformation of manufacturing--lessons from the apparel and textile industries*. Oxford University Press. P.130 Retrieved 23 December 2021.

Abrego, S. (2019) Cone Mills Denim: an investigation into fabrication, tradition, and quality, fashion theory. *Routledge Taylor Francis Group.* 23(4-5), 515-530, DOI: 10.1080/1362704X.2017.1420540

Achille, A., Remy, N., & Marchessou, S. (2018). The age of digital Darwinism. *Apparel, Fashion and Luxury Group.* McKinsey &Company. [REPORT] Retrieved https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/luxury%20in%20the%20age%20of%20digital%20darwinism/the-age-of-digital-darwinism.ashx

Adams, S. (2015). *Graphic Design History: The Arts and Crafts Movement* [Video]. LinkedIn Learning. https://www.linkedin.com/learning/graphic-design-history-the-arts-and-crafts-movement/the-industrial-revolution?autoAdvance=true&autoSkip=false&autoplay=true&resume=false&u=71337938

AIMS. (2020). Information and communication technologies (ICT). *AIMS.* 6/01/2021 Retrieved http://aims.fao.org/information-and-communication-technologies-ict

[a]industri. (2022). Open-Source Production Pattern Guidelines (OSPP). V1.4

Ali, A & Haseeb, M. (2019). Radio frequency identification (RFID) technology as a strategic tool towards higher performance of supply chain operations in textile and apparel industry of Malaysia. Uncertain Supply Chain Management, 7(2), 215-226. DOI: 10.5267/j.uscm.2018.10.004

Al-Kassab, J., Blome, P., Wolfram, G., Thiesse, F., & Fleisch, E. (2010). RFID in the apparel retail industry: a case study from Galeria Kaufhof. In Ranasinghe, D.C., Sheng, Q.Z, & Zeadally, S., *Unique Radio Innovation for the 21st century. Building Scalable and Global RFID Networks* (pp.1-32). Springer. DOI: 10.1007/978-3-642-03462-6_13

Amed, I. (2013). The fashion industry (still) has an image problem. https://www.businessoffashion.com/opinions/news-analysis/the-fashion-industry-still-has-an-image-problem/

Amed, I. Berg, A., Balchandani, A., Andrá, S., Devillard, S., Straub, M., Rölkens, R., Grunberg, J., Kersnar, J., & Crump, H. (2022). State of Fashion 2023. Accessed 24 November 2023. Retrieved from https://www.businessoffashion.com/reports/news-analysis/the-state-of-fashion-2023-industry-report-bof-mckinsey/

Amed, I., Berg, A., Harris, H., Hurtado, M., Petersents, S.A., Roberts, R., & Altable, C.S. (2021). State of Fashion Technology Report 2022. Mckinsey & Company. Accessed

24 November 2023 Retrieved from https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion-technology-report-2022

Armitage, J. (2023). Rethinking haute couture: Julien Fournié in the virtual worlds of the metaverse. *French Cultural Studies*, *34*(2), 129-146. https://doi.org/10.1177/09571558221109708

Arribas, V & Alfaro, J. (2016). Digital transformation of a small fashion house: a PLM implementation. International Fashion Conference. ISBN: 978-989-20-7053-7

Arribas, V & Alfaro, J. (2018). 3D technology in fashion: form concept to consumer. *Journal of Fashion Marketing and Management.* 22(2), pp.240-251. DOI 10.1108/JFMM-10-2017-0114

Atkinson, P & Hammersley, M. (2007). *Ethnography Principles in Practice.* (3rd ed.). Routledge Taylor and Francis Group.

Attaran, M. (2012). Critical success factors and challenges of implementing RFID in supply chain management. *Journal of Supply Chain and Operations Management.* 10(1): p.144-167. Retrieved https://www.researchgate.net/publication/281331964_Critical_success_factors_and_challenges_of_implementing_RFID_in_supply_chain_management

Azhar Iqbal, M. (2013). *Virtual Product Development and Management Opportunities in Fashion Industry* (Master's Thesis). Tampere University of Technology, Finland. Accessed 22 November 2023. Retrieved from https://trepo.tuni.fi/bitstream/handle/123456789/21982/Azhar%20Iqbal.pdf;jsessionid=EAFF43F598EE25480726C14C3CC048A6?sequence=3

Bao, J., Guo, D., Li, J., & Zhang, J. (2019) The modelling and operations for the digital twin in the context of manufacturing. *Enterprise Information Systems,* (13)4, p.534-556, DOI: 10.1080/17517575.2018.1526324

Barrie, L. (2015). Leveraging the business benefits of 3D virtual design. Just style. Retrieved 26 November 2023. Retrieved ttps://doi.org/10.1016/j.procir.2020.01.123

Bastos Porsani, G., Del Valle de Lersundi, K., Sánchez-Ostiz Gutiérrez, A., & Fernández Bandera, C. (2021). Interoperability between Building Information Modelling (BIM) and Building Energy Model (BEM). Applied Science, 11 (2167), p. 1-20. https://doi.org/ 10.3390/app11052167/

Bertola, P. & Teunissen, J. (2018). Fashion 4.0. Innovating the fashion industry through digital transformation. *Research Journal of Textile and Apparel*, 22(4), 352-369. DOI 10.1108/RJTA-03-2018-0023

Bhardwaj, V. & Fairhurst, A. (2010). Fast fashion: response to changes in the fashion industry. *The International Review of Retail, Distribution and Consumer Research.* 20(1) p.165-173. DOI: 10.1080/09593960903498300

Blanks, T. (2020). “Why Chanel doesn’t want to change the fashion system.” *Business of Fashion.* Retrieved https://www.businessoffashion.com/articles/professional/why-chanel-doesnt-want-to-change-the-fashion-system

Bonsignorio, F. & Molfino, R. (2006). An object based on virtual reality simulation tool for design validation of a new paradigm cloth manufacturing facility. In Shen W., Information Technology for Balanced Manufacturing Systems (pp.301-308). Boston Springer. file:///Users/55149681/Desktop/journal%20articles/978-0-387-36594-7_32.pdf

Bottani, E., Volpi, A., Rizzi, A., Montanari, R., & Bertolini, M. (2014). "The role of radio frequency identification (RFID) technologies in improving distribution and retail operations in the fashion supply chain" in *Elsevier Science & Technology.* P.13-41.DOI: 10.1533/9780857098115.13

Breward, C. (2003). *Fashion.* Oxford: OUP Oxford. [eBook] Retrieved http://search.ebscohost.com.salford.idm.oclc.org/login.aspx?direct=true&AuthType=shib,cookie,ip,url,uid&db=nlebk&AN=811690&custid=s2888710

Browzwear. (2022). "What is digital product creation in the fashion industry?" *Browzwear Solutions.* Retrieved https://browzwear.com/blog/what-is-digital-product-creation-in-the-fashion-industry

Bruce, M. & Daly, L. (2006). Buyer behaviour for fast fashion. *Journal of Fashion Marketing and Management.* 10(3), p. 329-344. DOI 10.1108/13612020610679303

Buyukaslan, E., Jevsnik, S., & Kalaoglu, F. (2018). Comparative analysis of drape characteristics of actually and virtually draped fabrics. *International Journal of Clothing Science and Technology.* 30 (3), p. 286-301. DOI 10.1108/IJCST-06-2017-0085

Cabigiosu, A. (2020). Additive Manufacturing and Smart Textiles. In: Digitalization in the Luxury Fashion Industry. Palgrave Advances in Luxury. Palgrave Macmillan, Cham. https://doi-org.salford.idm.oclc.org/10.1007/978-3-030-48810-9_6

Carr, V.H. (1999) Technology adoption and diffusion. The Learning Center for Interactive Technology. Retrieved https://www.icyte.com/system/snapshots/fs1/9/a/5/0/9a50b695f1be57ce369534ac73785801745a8180/index.html

Casciani, D., Chkanikova, O., & Pal, R. (2022). Exploring the nature of digital transformation in the fashion industry: opportunities for supply chains, business models, and sustainability oriented innovations.

Casciani, D. & Wang, H. (2022). Practising the work of a sustainable digital fashion designer/maker 4.0: design of an organic and modular clothing system based on the Industry 4.0 approach. GFC 22 Global Fashion Conference. DOI: 10.57649/GFC.978-989-54263

Chen, Y. (2023). How blockchain adoption affects supply chain sustainability in the fashion industry: a systematic review and case studies. *International Transactions in Operational Research.* DOI: 10.1111/itor.13273

Choi, T.M., Yeung, W.K., Cheng, E., & Yue, X. (2018). Optimal scheduling, coordination, and the value of RFID technology in garment manufacturing supply chains. IEEE Transactions on Engineering Management. 65(1), p.72 -84. DOI: 10.1109/TEM.2017.2739799

Choi, Y. (2015). Size specification for customised production size and 3D avatar: an apparel industry case study. *Fashion and Textile Resource Journal.* 17(2). 278-286. Retrieved from https://doi.org/10.5805/SFTI.2015.17.2.278

Christensen, C.M & Bower, J.L. (1996). Customer power, strategic investment, and the failure of leading strategy management. 17, p.197-218. https://doi.org/10.1002/(SICI)1097-0266(199603)17:3<197::AID-SMJ804>3.0.CO;2-U

Clark, R. & Estes, F. (1998). Technology or craft: what are we doing? Educational Technology Publications, Inc. 38(5). Retrieved https://www.jstor.org/stable/44428476

Cone Denim. (2022). *The denim manufacturing process.* [Pamphlet].

Conlon, J. (2019). From PLM 1.0 to PLM 2.0: the evolving role of product lifecycle management (PLM)in the textile and apparel industries. Journal of Fashion Marketing and Management: An International Journal. 24(4), pp. 533-553. DOI 10.1108/JFMM-12-2017-0143 Retrieved 23 December 2021.

Conlon, J. & Gallery, C. (2023). Developing digital skills: a fashion business masterclass in virtual 3D prototyping with Style3D, International Journal of Fashion Design, Technology and Education, DOI: 10.1080/17543266.2023.2247425

Coster, J.D. (2006). Leapfrog project wages a race against time. Just-style. Accessed 26 November 2023. Retrieved from https://www.just-style.com/comment/leapfrog-project-wages-a-race-against-time/?cf-view

Coughlin, P., Rubin, M., & Darga, L. (2001). "Constraints & opportunities. Myopia or global vision?" *The SADC Textile and Garment Industries.* Retrieved https://www.researchgate.net/publication/238771029_The_SADC_Textile_and_Garment_Industries_Constraints_Opportunities_Myopia_or_Global_Vision

Cowles, E. & Nelson, E. (2019). History of surveys: Cowles. *An introduction to survey research. Volume I, Basics of survey research* (Second ed). P.9

Creswell, J.W. (2009). *Research design: Qualitative, Quantitative, and Mixed Methods Approaches* (3rd ed.). SAGE Publications.

Crofton, S.0. & Dopico, L. (2007). Zara-Inditex and the growth of fast fashion. *Essays in Economic and Business History.* 25(1). p. 41-54. Retrieved https://www.researchgate.net/profile/Luis_Dopico/publication/262048389_Zara-Inditex_and_the_Growth_of_Fast_Fashion/links/55dc9d4108ae9d659494f818/Zara-Inditex-and-the-Growth-of-Fast-Fashion.pdf

Cumming, & Kaplan, W. (1991). *The arts and crafts movement.* Thames and Hudson.

Damen, M.A., Stepke-Müller, M., Meyer zum Felde, A., Rubel, H., Turner J., Van Doorne, L., Sukailo, D., Holtorf, M., & Eggert, F. (2023). The EU digital product passport shapes the future of value chains: what it is and how to prepare now. World Business Council for Sustainable Development and Boston Consulting Group. Retrieved from https://www.wbcsd.org/contentwbc/download/15584/226479/1

D'Apuzzo, N. (2009). Recent advances in 3D full body scanning with applications to fashion and apparel in Optical 3-D Measurement Techniques IX. Austria. https://www.hometrica.ch/publ/2009_optical3d.pdf Retrieved 23 December 2021.

Davey, I. (2020). "Technology's potential to make your brand more sustainable" *Jing Daily.* Retrieved https://jingdaily.com/technologys-potential-to-make-your-brand-sustainable/?utm_medium=social&utm_source=linkedin.company&utm_campaign=postfity&utm_content=postfitycf2b9

Davis, F.D. (1986). *A technology acceptance model for empirically testing new end-user information systems: theory and results.* [Doctoral dissertation, Massachusetts Institute of Technology, Sloan School of Management]. MIT Libraries. http://hdl.handle.net/1721.1/15192

Dedehayir, O & Steinert, M. (2016). The hype cycle model: a review and future directions. *Technological Forecasting & Social Change.* 108, 28-41. http://dx.doi.org/10.1016/j.techfore.2016.04.005

Denuwara, N., Maijala, J., & Hakovirta, M. (2019). Sustainability benefits of RFID technology in the apparel industry. *MDPI Journal of Sustainability.* 11(6477), p.1-14. doi:10.3390/su11226477

Depince, P., Chablat, D., Noel, E., & Woelk, P.O. (2004). The virtual manufacturing concept: scope, socio-economic aspects, and future trends. 2004 ASME Design Engineering Technical Conferences and Computers and Information in Engineering Conferences. https://doi.org/10.48550/arXiv.0707.2841

Dillon, S. (2018). *The fundamentals of fashion management.* 2 Edition. Bloomsbury Visual Arts. [EBOOK]. Lausanne, Switzerland: AVA.

Doreinger, P & Crean, S. (2005). Can fast fashion save the US apparel industry. *Socio-economic Review.* 4 (1), p. 353-377. [PDF] https://www.semanticscholar.org/paper/Can-Fast-Fashion-Save-the-Us-Apparel-Industry-Doeringer-Crean/78d13d4d1a617ebb93c8bdf28404715133db68fe

Drucker, P.F. (1994). The theory of the business. *Harvard Business Review. https://hbr.org/1994/09/the-theory-of-the-business*

Duarte, A., Sanches, R., & Dedini, F. (2018). "Assessment and technological forecasting in the textile industry: from first industrial revolution to the industry 4.0". *Strategic Design Research Journal.* 11(3), pp.193-202. doi: 10.4013/sdrj.2018.113.03

DuBreuil, M & Lu, S. (2020). Traditional vs. big-data fashion trend forecasting: an examination using WGSN and EDITED. *International Journal of Fashion Design, Technology and Education.* 13(1), p. 68-77. 7, DOI: 10.1080/17543266.2020.1732482

Easters, D. (2012). Global communication part 1: the use of apparel CAD technology. *International Journal of Fashion, Design, Technology and Education.* 5(1) 45-54. http://dx.doi.org/10.1080/17543266.2011.607851

Easey, M. (2011). Fashion marketing. Wiley-Blackwell: UK. 3rd ed.

Economic & Social Research Council. (2023). https://esrc.ukri.org/public-engagement/social-science-for-schools/resources/what-is-social-science-research/

Ellen MacArthur Foundation. (2017). What is the circular economy. *The Ellen MacArthur Foundation.* Retrieved https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

Elliot, F. (2017). "Weaving numbers: the jacquard loom and early computing." *Science and Industry Museum Group.* Retrieved https://blog.scienceandindustrymuseum.org.uk/weaving-numbers-jacquard-loom-early-computing/.

Essinger, J. (2007). *Jacquard's Web: How a Hand-Loom Led to the Birth of the Information Age*. Oxford University Press, Incorporated. [Ebook]. http://ebookcentral.proquest.com/lib/salford/detail.action?docID=422876.

European Commission. (2023). Proposal for a directive of the European Parliament and the Council. (COM (2023)166 final). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A0166%3AFIN

European Environment Agency. (2023). *Textiles in Europe's circular economy.* https://www.eea.europa.eu/publications/textiles-in-europes-circular-economy/textiles-in-europe-s-circular-economy

European Parliament. (2024). *The impact of textile production and waste on the enviornment (infographics).* https://www.europarl.europa.eu/topics/en/article/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics

Fairey, A. (2023). The rise of fashion NFTs. *Commonwealth Fashion Council.* Retrieved https://commonwealthfashioncouncil.org/the-rise-of-fashion-nfts/

Fashion For Good. (2020). Financing the transformation in the fashion industry. Unlocking investment to scale innovation. *Fashion for Good and Boston Consulting Group.* [PDF]. Retrieved from https://fashionforgood.com/wp-content/uploads/2020/01/FinancingTheTransformation_Report_FINAL_Digital-1.pdf

Fashion for Good, Parker, G. & Jae Slooten, A. (2020). *Digital futures: taking fashion online* [Webinar]. Fashion for Good. Retrieved https://www.youtube.com/watch?v=moHTzv4DleM&feature=youtu.be

Fernandez-Stark, K., Frederick, S. & Gereffi, G. (2011). The apparel global value chain: economic upgrading and workforce development. Duke University. *Centre on Globalization, Governance & Competitiveness.* [PDF] Retrieved https://gvcc.duke.edu/wp-content/uploads/2011-11-11_CGGC_Apparel-Global-Value-Chain.pdf

Fettermann, D.C., Sá Cavalcante, C.G., Almeida, T.D. & Tortorella, G.L. (2018). How does Industry 4.0 contribute to operations management? *Journal of Industrial and Production Engineering,* 35(4), p. 255-268, DOI: 10.1080/21681015.2018.1462863

Freund, R. (2008). Mass Customisation, personalisation, and contextualised multiple competencies. 3rd International Conference on Mass Customisation and Personalisation in Central Europe (MCP–CE). 3-6 June 2008, Serbia. P.1-6. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=80b2da8f577fbd7114a885cd6136e80754b7dab4

Ganji, E., Shah, S., & Coutroubis, A. (2018). “DCM 4.0: integration of industry 4.0 and demand chain in global manufacturing.” *IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC).* DOI: 10.1109/ICE.2018.8436383

Gartner Inc. (2018). *Hype Cycle for Emerging Technologies, 2018*. Gartner. Retrieved November 12, 2023, from https://www.gartner.com/en/documents/3885468

Ghoreishi, M., Happonen, A., & Pynnönen, M. (2020). Exploring Industry 4.0 Technologies to Enhance Circularity in Textile Industry: Role of Internet of Things, In Twenty-first International Working Seminar on Production Economics. Innsbruck. pp. 1-16, doi: 10.5281/zenodo.3471421

Giannakis, M., Spanaki, K., & Dubey, R. (2019). A cloud-based supply chain management system: Effects on supply chain responsiveness. Journal of Enterprise Information Management, 32(4), 585-607. doi:http://dx.doi.org.salford.idm.oclc.org/10.1108/JEIM-05-2018-0106

Gill, S., Hayes, S., & Parker, C. (2016). 3D body scanning: towards shared protocols for data collection. *International Workshop of Advanced Manufacturing and Automation.* Atlantis Press, p.281–284. DOI: 10.2991/iwama-16.2016.53

Gonzalo, A., Harris, H., Altable, C.S., & Villepelet, C. (2020). Fashion's digital transformation: now or never. *McKinsey & Company.* p.1–11. Retrieved https://www.mckinsey.com/~/media/McKinsey/Industries/Retail/Our%20Insights/Fashions%20digital%20transformation%20Now%20or%20never/Fashions-digital-transformation-now-or-never-VF.pdf

Hall, C. (2020). "Now is the time for virtual showrooms to shine. Will they?" *Business of Fashion.* Retrieved https://www.businessoffashion.com/articles/professional/now-is-the-time-for-virtual-showrooms-to-shine-will-they?utm_source=linkedin&utm_medium=social

Hammersley, M & Atkinson, P. (2007). *Ethnography Principles in practice.* (3rd ed.) Taylor and Francis.

Hanelt, A., Piccinini, E., Gregory, R.W., Hildebrandt, B. & Kolbe, L.M. (2015), "Digital transformation of primarily physical industries: exploring the impact of digital trends on business models of automobile manufacturers", in Thomas, O. and Teuteberg, F. (Eds), Proceedings of 12th International Conference on Wirtschaftsinformatik (WI 2015) in Osnabrück, Germany, Universität Osnabrück, Osnabrück, pp. 1313-1327.

Hatzichronoglou, T. (1997). Revision of the High-Technology Sector and Product Classification. *IDEAS Working Paper Series from RePEc,* IDEAS Working Paper Series from RePEc, 1997. Retrieved https://ideas.repec.org/p/oec/stiaaa/1997-2-en.html

Haworth, D. (2015). "The fashion industry is "saturated" says Olivier Theyskens". *Dezeen.* Retrieved https://www.dezeen.com/2015/01/30/olivier-theyskens-interview-fashion-industry-saturated-seoul-design-week-2014/

Hayes, B. (2008). Measuring customer satisfaction and loyalty: Survey design, use, and statistical analysis methods (3rd ed.).

Hegde, M.G. (2018). Creation of future digital fashion world by interdisciplinary approach of the artisans – a perspective. Journal of Textile and Clothing Science. 1(2) p.1–6. ISSN (Online): 2581-561X

Heidegger, M. (1977). "The question concerning technology and other essays." Garland Publishing INC.: New York and London. [PDF] Retrieved http://pdf.zlibcdn.com/dtoken/3ec86f80c12109d5df9de823d8a3a142/The_Question_Concerning_Technology_and_Other_Essay_2064520_(z-lib.org).pdf.

Hermann, M., Pentek, T., & Otto, B. (2015). Design Principles for Industry 4.0 Scenarios: A Literature Review. DOI: 10.13140/RG.2.2.29269.22248.

Hinds, B. & McCartney, J (1990). Interactive garment design. *The Visual Computer* 6, 53–61 Retrieved https://doi-org.salford.idm.oclc.org/10.1007/BF01901066

Hines, T. (2004). *Supply chain strategies customer driven and customer focused.* Oxford: Butterworth-Heinemann. P.286

Hirvonen, P., D. Rellstab & N. Siponkoski (2016). Affectivity in fashion magazines: designer stories and the production of gender through emotional intensity. VAKKI-symposium 36 (11). VAKKI Publications, p.83-94.

Hoang, L. (2016). "How Burberry is operationalising 'see now, buy now'". *Business of Fashion.* Retrieved https://www.businessoffashion.com/articles/intelligence/how-burberry-is-operationalising-see-now-buy-now

Hobbs, J. (2020). Fashion week isn't cancelled– it's happing on animal crossing. *Vogue UK.* Retrieved https://www.vogue.co.uk/arts-and-lifestyle/article/fashion-week-animal-crossing

Holt, R. & Yamauchi, Y. (2019). "Craft, design and nostalgia in modern Japan- the case of sushi" in *The Organization of Craft Work.* pp. 19-40. Routledge New York and London.

Hoque, M.A., Rasiah, R., Furoka, F., & Kumar, S. (2020). Technology adoption in the apparel industry: insight from literature review and research directions." *Research Journal of Textile and Apparel.* 25(3), pp. 292-307. DOI 10.1108/RJTA-08-2020-0090

Howell, G. (2012). *Wartime fashion: from haute couture to homemade, 1939-1945.* Berg.

Huggard, E. & Sarmakari, N. (2023). *How digital-only fashion brands are creating more participatory models of fashion co-design. Fashion, Style, & Popular Culture,* 10(4), p.583-600. DOI: https://doi.org/10.1386/fspc_00176_1

Hwang, J.Y. & Hahn, K.H. (2017). A case study of 2d/3d cad virtual prototype simulation programs to enhance student performance in student-centred fashion design education. J Textile Eng Fashion Technol. 2017;3(1):578–584. DOI: 10.15406/jteft.2017.03.00088

Istook, C.L, Newcomb, E.A, & Lim, H. (2011). "14 - Three-dimensional (3D) technologies for apparel and textile design" In Computer Technology for Textiles and Apparel. Woodhead Publishing. (pp. 296-325). https://doi.org/10.1533/9780857093608.3.296

Jhanji, Y. (2018). CH. 11 Computer-aided design– garment designing and patternmaking. The Textile Institute Book Series. P.253–290. https://doi.org/10.1016/B978-0-08-101211-6.00011-2

Johnston, R. & Lawrence, P. (1988). Beyond vertical integration- the rise of the value-adding partnership. *Harvard Business Review.* [PDF] p. 1-17. Retrieved https://hbr.org/1988/07/beyond-vertical-integration-the-rise-of-the-value-adding-partnership#:~:text=to%20be%20felt.-,That%20beast%20is%20the%20%E2%80%9Cvalue%2Dadding%20partnership%E2%80%9D%E2%80%94a,the%20entire%20value%2Dadded%20chain.

Joshi, A., Kale, S., Chandel, S., & Pal, D.K. (2015). Likert scale: explored and explained. *British Journal of Applied Science & Technology.* 7 (4), p. 396-403. DOI: 10.9734/BJAST/2015/14975

Kaiser, C., Fischer, T., Schmeltzpfenning, T., Stohr, M. & Artschwager, A. (2014). Case study: mass customisation of individualised orthotics- the FASHION-ABLE virtual development and production framework. *Procedia CIRP.* 21(1). Pp.105-110. https://doi.org/10.1016/j.procir.2014.03.189

Kalypso: A Rockwell Automation Company. (2020). *2020 annual survey: digital product creation maturity in retail, footwear, and apparel.* https://kalypso.com/retail2020

Kalton, G. (2019). Developments in Survey Research over the Past 60 Years: A Personal Perspective. *International Statistical Review, 87*(S1), S10-S30.

Kaplandidou, A. (2018). *Digitalization in the apparel manufacturing process* (Master's Thesis). University of Utrecht, Greece. Accessed 22 November 2023. Retrieved https://studenttheses.uu.nl/handle/20.500.12932/39255

Kapla, W. & Crawford, A. (2004). *The arts & crafts movement in Europe & America: design for the modern world.* Thames & Hudson.

Keiningham, T., He., Z., Hillebrand, B., Jang, J., Suess, C. & Wu, L. (2019). "Creating innovation that drives authenticity". Journal of Service Management. 30(3), pp.369-391. DOI 10.1108/JOSM-12-2018-0383

Kim, J., Kim, Y., Shim, M., Jun, Y. & Yun, C. (2020). Prediction and categorization of fabric drapability for 3D garment virtualization. *International Journal of Clothing Science and Technology.* 32 (4), p. 523-535. DOI 10.1108/IJCST-08-2019-0126

Kim, J. & Forsythe, S. (2009). "Adoption of sensory enabling technology for online apparel shopping." *European Journal of Marketing.* 43(9/10) pp 1101-1120. DOI 10.1108/03090560910976384

Kim, Y. & Park, H. (2012) A study of the relationship between 3D and 3D garment simulation. *Journal of Korean Society of Clothing and Textiles.* 36 (23), p. 631-640

Ko, E., Kim, S.H., Kim, M., & Woo, J. (2007). "Organisational characteristics and the CRM adoption process." *Journal of Business Research.* 61, p.65-74. doi:10.1016/j.jbusres.2006.05.011

Kotha, S & Swamidass, P. (2000). Strategy, advanced manufacturing technology and performance: empirical evidence from U.S. manufacturing firms. *Journal of Operations Management.* 18(3). Pp. 257-277. https://doi.org/10.1016/S0272-6963(99)00025-X

Kristav, P. & Diegel, O. (2017). "Authenticity in product development." The International Conference on Design and Technology, KEG, pp.51-58. DOI 10.18502/keg.v2i2.595

Kuusk, K., Wensveen, S., & Tomico, O. (2016). Craft qualities translated from traditional crafts to smart textile services. *Studies in Material Thinking*, 14, (5). Retrieved https://research.tue.nl/en/publications/craft-qualities-translated-from-traditional-crafts-to-smart-texti

Keung Kwok, S. & Wu, K.K.W. (2009). RFID-based intra-supply chain in textile industry. *Industrial Management & Data Systems*. 109 (9), pp. 1166-1178. https://doi.org/10.1108/02635570911002252

Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W. (2018). Digital twin in manufacturing: a categorical literature review and classification. *International Federation of Automatic Control IFAC.* 51(11), p.1016-1022. https://doi.org/10.1016/j.ifacol.2018.08.474

Lechman, D., O'Connor, K., Lockwood, C., & Caroll, G. (2019). The dark side of authenticity in organisational life. Academy of Management Annals. 13(1) p.1-42.

Lee, H. & Leonas, K.K. (2018). Consumer experiences, the key to surviving in an omni-channel environment: use of virtual technology. *Journal of Textile and Apparel, Technology and Management.* 10(3), p.1–23. Accessed 21 November 2023 from https://jtatm.textiles.ncsu.edu/index.php/JTATM/article/viewFile/13353/5997

Lee, E. & Jordan, I. (2021) Having the right DNA for change: case studies from 3D implementation in fashion. *MOTIF.* [Webinar].

Lee, Y.A. (2022). Trends of Emerging Technologies in the Fashion Product Design and Development Process. In: Lee, YA. (eds) Leading Edge Technologies in Fashion Innovation. Palgrave Studies in Practice: Global Fashion Brand Management. Palgrave Macmillan, Cham. https://doi-org.salford.idm.oclc.org/10.1007/978-3-030-91135-5_1

Lee, M., Yun, J., Pyka, A., Won, D., Kodama, F., Schiuma, G., Park, H., Jeon, J., Park, K., Jung, K., Yan, M., Lee, S., & Zhao, X. (2018). "How to respond to the fourth industrial revolution or the second information technology revolution? Dynamic new combinations between technology, market, and society through open innovation." *Journal of Open Innovation: Technology, Market, and Complexity.* 4(21), pp.1-24. doi:10.3390/joitmc4030021

Lee, K., Udin, Z. & Hassan, M. (2014). "Supply chain technology adoption: its clarification, evolution, classification, and practicality in textile and apparel industry." *International Journal of Business and Economics.* 3(6-1) p. 15-21. doi: 10.11648/j.ijber.s.2014030601.13

Leeuw, E. (2005). To mix or not to mix data collection modes in surveys. *Journal of Official Statistics.* 21(2). P.233-255.

Ley, K. (2020). "Promising areas for innovation in COVID-19 times: part 2." *Fashion for Good.* Retrieved https://medium.com/fashion-for-good/promising-areas-for-innovation-in-covid-19-times-part-2-182cdbf0bbc0

Lim, L. (2020). *MA fashion design talk- Lena Lim, BrowZwear* [Webinar]. University of Salford.

Linden, A. & Fenn, J. (2003). *Understanding Gartner's Hype Cycles.* [Report No. R-20-1971]. Garner Research. http://ask-force.org/web/Discourse/Linden-HypeCycle-2003.pdf

Loh, P., Burry, P., & Wagenfeld, M. (2016). Reconsidering Pye's theory of making through digital craft practice: a theoretical framework towards continuous designing. *Craft Research.* 7 (2), p. 187-206. doi: 10.1386/crre.7.2.187_1

Loomis, D. & Paterson, S. (2018). A comparison of data collection methods: Mail versus online surveys. *Journal of Leisure Research, 49*(2), 133-149.

Luce, I. (2018). *Artificial Intelligence for Fashion: How AI Is Revolutionising the Fashion Industry*. 1st e.d. Berkeley, CA: Apress. L. P. ProQuest eBook Central. Retrieved http://ebookcentral.proquest.com/lib/salford/detail.action?docID=5611900

MacCallum, F., Widdows, H. Altered Images: Understanding the Influence of Unrealistic Images and Beauty Aspirations. *Health Care Anal* 26, 235–245 (2018). https://doi-org.salford.idm.oclc.org/10.1007/s10728-016-0327-1

Maksimovic, N. (2020). Methods to digitising physical properties for virtual simulation. *Tekstilna Industrija.* p.36-43. doi: 10.5937/tekstind2003036M

McDermott, C., & Stock, G. (1999). Organisational culture and advanced manufacturing technology implementation. *Journal of Operations Management*. 17(5) pp. 521-533. https://doi.org/10.1016/S0272-6963(99)00008-X

McDowell, M. (2020). Gabriela Hearst is giving its spring collection a digital identity. *Vogue Business.* Retrieved from https://www.voguebusiness.com/sustainability/gabriela-hearst-eon-circularid

McKinsey & Company and Business of Fashion (2024). *The state of fashion 2024.* https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion#/

McLaren, T., Head, M., & Yuan, Y., “Using competitive strategy patterns to determine ideal supply chain management information systems capabilities,” *Int. J. Internet Enterprise Management.*, 2(1) pp. 45–61, 2004.

Meade, P.T. & Rabelo, L. (2004) The technology adoption life cycle attractor: Understanding the dynamics of high-tech markets. *Technological Forecasting & Social Change.* 71. pp. 667-684. doi:10.1016/j.techfore.2004.01.008

Miller, C.R. (1998). Learning from history, World War II and the culture of high technology. *Journal of Business and Technical Communication.* 12(3), p.288-315. https://doi-org.mmu.idm.oclc.org/10.1177/10506519980120030

Milner, D. (2021, April 05). Video tutorials and virtual design: fashion education's hybrid future. *Business of Fashion.* Accessed 23 November 2023. Retrieved https://www.businessoffashion.com/articles/workplace-talent/video-tutorials-and-virtual-design-fashion-educations-hybrid-future/

Milnes, H. (2022). LVMH’s Arnault is wary of the metaverse “bubble”. Should luxury be? *Vogue Business.* Accessed 9 Feb 2022. Retrieved https://www.voguebusiness.com/companies/lvmhs-arnault-is-wary-of-the-metaverse-bubble-should-luxury-be

Morrar, R., Arman, H., & Mousa, S. (2017). The fourth industrial revolution (Industry 4.0): a social innovation perspective. *Technology Innovation Management Review.* 7(11), p. 12–20. DOI:10.22215/timreview/1117

Mustonen, N. (2013). *Fashion openness: applying an open source philosophy to the paradigm of fashion.* [Master’s Thesis, Aalto University]. Aaltodoc. https://aaltodoc.aalto.fi/handle/123456789/10357

Nafz, R., Schinle, C., Kaiser, C., & Kyosev, Y.K. (2022). Digital transformation of the textile process chain – state-of-the-art. Communications in Development and Assembling of Textile Products. 3(2), pp.79–89. DOI 10.25367/cdatp.2022.3.

Nayak, R. & Padhye, R. (2015) "Chapter 1: introduction: the apparel industry." *Garment Manufacturing Technology.* Woodhead Publishing Series in Textiles. [eBook]. Pp.1-17 DOI: https://doi.org/10.1016/B978-1-78242-232-7.00001-1

Newman, G. (2019). "The psychology of authenticity." *Review of General Psychology. American Psychological Association.* 23(1) 8-18. DOI: 10.1037/gpr0000158 journals.sagepub.com/home/rgp

Niinimaki, K. (2013). *Sustainable fashion: new approaches.* Aalto University publication series. Helsinki: Finland. [eBook]. Retrieved https://aaltodoc2.org.aalto.fi/bitstream/handle/123456789/13769/isbn9789526055732.pdf?sequence=1&isAllowed=y

Nobile, T.H., Noris, A., Kalbaska, N., & Cantoni, L. (2021) A review of digital fashion research: before and beyond communication and marketing. *International Journal of Fashion Design, Technology and Education.* 14(3), pp. 293-301. DOI:10.1080/17543266.2021.1931476

Noris, A., San Miguel, P., & Cantoni, L. (2020). Localization and cultural adaptation on the web: an explorative study in the fashion domain. IN: Nah, F.H., Siau, K. HCI in Business, Government, and Organizations. HCII 2020. Lecture Notes in Computer Science. 12204. Springer, Cham. DOI https://doi.org/10.1007/978-3-030-50341-3_36

O'Neil, L. (2020). A five-minute history of fast fashion in the UK. *Vice Media Group.* Retrieved https://www.vice.com/en/article/xg8jyq/nvidias-3080-video-cards-ps5-sold-out

OpenAI. (2015). DALLE: Creating images from text. *OpenAI.* Retrieved https://openai.com/research/dall-e

Papahristou, E. (2016). *The Effective Integration of 3D Virtual Prototype in the Product Development Process of the Textile/Clothing Industry* (PhD Thesis). Technical University of Create School of Production Engineering & Management, Greece. Accessed on 22 November. Retrieved from https://pdfs.semanticscholar.org/4b2a/2581a6823633143e41509a94f21007e6b34c.pdf

Papachristou, E. & Billalis, N. (2016). Can 3D virtual prototypes conquer the apparel industry? *Journal of Fashion Technology and Textile Engineering.* 4(1). 1-7. DOI: 10.4172/2329-9568.1000134

Papahristou, E & Bilalis, N. (2017). "3D virtual prototyping traces new avenues for fashion design and prototyping development: a qualitative study." *Journal of Textile Science and Engineering.* 7(2), pp. 1-6. doi: 10.4172/2165-8064.1000297

Papahristou, E., Kyratsis, P., Priniotakis, G., & Bilalis, N. (2017). The interconnected fashion industry- an integrated vision. 17th World Textile Conference. Conference Series: Materials Science and Engineering. 254. *AUTEX. IOP Publishing.* doi:10.1088/1757-899X/254/17/172020

Park, J., Kim, D. & Sohn, M. (2011). 3D simulation technology as an effective instructional tool for enhancing spatial visualisation skills in apparel design. *International Journal of Technology and Design Education*, 21(4), pp.505–517. https://doi-org.salford.idm.oclc.org/10.1007/s10798-010-9127-3

Parker-Strak, R. & Barnes, L. (2020). Disruptive product development for online fast fashion retailers. *Journal of Fashion Marketing and Management: An International Journal.* 24(3). P.517-532. Retrieved DOI 10.1108/JFMM-08-2019-0170

Pasricha, A. & Greeninger, R. (2018). Exploration of 3D printing to create zero-waste sustainable fashion notions and jewellery. *Fashion Text.* 5 (30). Retrieved https://doi-org.salford.idm.oclc.org/10.1186/s40691-018-0152-2

Petro, G. (2012). “The future of fashion retailing: the Zara approach (part 2 of 3)”. *Forbes.* Retrieved https://www.forbes.com/sites/gregpetro/2012/10/25/the-future-of-fashion-retailing-the-zara-approach-part-2-of-3/#3324f17b7aa4

Phillips, P., & Stawarski, C. (2008). *Data Collection: Planning for and Collecting All Types of Data*, Center for Creative Leadership. [*ProQuest eBook Central*] Retrieved http://ebookcentral.proquest.com/lib/salford/detail.action?docID=331440.

Piboonrungroj, P, Williams, S. & Simatupang, T. (2017). The emergence of value chain thinking. *International Journal of Value Chain Management.* 8(1). p.1-40. DOI 10.1504/IJVCM.2017.10003558.

Press, C. (2020). Eva Kruse, fashion’s force of nature, fronts the men in suits. *Financial Review.* Retrieved from https://www.afr.com/life-and-luxury/fashion-and-style/eva-kruse-fashion-s-force-of-nature-fronts-the-men-in-suits-20200204-p53xqy

Prisecaru, P. (2016). “Challenges of the fourth industrial revolution.” *Knowledge Horizons-Economics.* 8(1), pp.57-62. Retrieved https://search-proquest-com.salford.idm.oclc.org/docview/1793552558?accountid=8058

Punch, K. (2003). Survey research the basics (Essential resources for social research). London; Thousand Oaks, CA: Sage Publications.

Quinn, L., Hines, T., & Bennison, D. (2007). Making sense of market segmentation: a fashion retailing case. *European Journal of Marketing.* 41(56). P.439-465. DOI 10.1108/03090560710737552

Rammert, W. (1992). From mechanical engineering to information engineering perspective. *New Technology at the Outset: Social Forces in the Shaping of Technological Innovations.* P.193-205. Ed. Meinolf Dierkes and Ute Hoffman. Frankfurt, Germany. Retrieved https://www.researchgate.net/publication/240006779_From_mechanical_engineering_to_information_engineering_An_evolutionary_perspective

Rathinamoorthy, R. (2019). Consumer’s awareness on sustainable fashion. In: Muthu S. (eds) Sustainable Fashion: Consumer Awareness and Education. Textile Science and Clothing Technology. Pp.1-36. Springer, Singapore. Retrieved https://doi.org/10.1007/978-981-13-1262-5_1

Riedelsheimer, T., Dorfhuber, L., & Stark, R. (2020). User centred development of a digital twin concept with focus on sustainability in the clothing industry. *27th CIRP Life Cycle Engineering Conference (LCE2020) Advancing Life Cycle Engineering: from technological eco-efficiency to technology that supports a world that meets the development goals and the absolute sustainability.* 90, p.660–665. https://doi.org/10.1016/j.procir.2020.01.123

Riordan, S & Yester, W. (2019). Eight common 3D digital product creation pitfalls and how to avoid them. *Kalypso.* Accessed 5 January 2022. Retrieved https://kalypso.com/viewpoints/entry/eight-common-3d-digital-product-creation-pitfalls-and-how-to-avoid-them

Rogers, E.M. (1995). *Diffusions of innovations* (4th ed). The Free Press.

Ross, P.T. & Bibler Zaidi, N.L. (2019). Limited by our limitations. *Perspectives on Medical Education.* 8(4), pp.261-264. https://doi.org/10.1007/s40037-019-00530-x

Rudolf, A., Cupar, A., & Stjepanovic, Z. (2019). Supporting digitalisation in garment engineering through virtual prototyping. 9th International Conference TexTec. DOI: 10.35530/TT.2019.02

Rutsky, R. (1999). *High Techne Art and Technology from the Machine Aesthetic to the Posthuman* [EBOOK] 2nd Edition. Minneapolis: University of Minnesota Press.

Santos, L., Neto, M. & Montagna, G. (2020). “The virtualization of the fashion product.” In Advances in Industrial Design. Pp.820-830. DOI: 10.1007/978-3-030-51194-4_106

Särmäkari, N. (2021). Digital 3D fashion designers: cases of Atacac and The Fabricant. https://doi-org.salford.idm.oclc.org/10.1080/1362704X.2021.1981657 pg85-114

Scaturro, S. (2015) Eco-tech Fashion: Rationalizing Technology in Sustainable Fashion. *Fashion Theory: The Journal for Dress, Body, and Culture.* 12(4), pp.469-488. DOI: 10.2752/175174108X346940

Sayem, A.S. (2022). Digital fashion innovations for the real world and metaverse, International Journal of Fashion Design, Technology and Education, 15:2, 139-141, DOI: 10.1080/17543266.2022.2071139

Sayem, A.S, Kennon, R., & Clarke, N. (2010). 3D CAD systems for clothing industry. *International Journal of Fashion Design, Technology and Education.* 3(2). P.45-53. https://doi-org.salford.idm.oclc.org/10.1080/17543261003689888

Schaer, C. (2020). Tipping point: the ‘gamification’ of fashion is accelerating. *Women's Wear Daily WWD.* Accessed 20 April 2020. Retrieved https://wwd.com/feature/tipping-point-the-gamification-fashion-accelerating-egames-1203556945/

Senanayake, M. (2015). “Product development in the apparel industry”, in *Garment Manufacturing Technology,* Woodhead Publishing in Textiles, pp. 21-57. Retrieved https://doi.org/10.1016/C2013-0-16494-X

Shanks, G & Bekmamedova, N. (2018). Chapter 7 case study research in information systems. (Second edition). In Williamson, & Johanson, G. (2018). *Research methods: information, systems, and contexts* (pp 379-403). Elsevier, Chandos Publishing.

Sherman, L. (2018). “The new fundamentals of manufacturing.” *Business of Fashion.* Retrieved https://www.businessoffashion.com/articles/professional/the-new-fundamentals-of-manufacturing

Smith, M. & Weil, D. (2005). “Ratcheting up: linked technology adoption in supply chains.” *Industrial Relations.* 44(3). p 490-508. https://doi-org.salford.idm.oclc.org/10.1111/j.0019-8676.2005.00396.x

Smith, P., Baille, J., & McHattie, L. (2017) Sustainable design futures: an open design vision for the circular economy in fashion and textiles. *The Design Journal.* DOI: 10.1080/14606925.2017.1352712

Socha, M. (2020). Will Fashion Finally Complete Its Digital Transformation? WWD: Women’s Wear Daily, 6–9. Retrieved http://search.ebscohost.com.salford.idm.oclc.org/login.aspx?direct=true&AuthType=shib,cookie,ip,url,uid&db=buh&AN=143504078&custid=s2888710 Trade Publication

Stapelton, T. & Lindauer, B. (2023). *VibeIQ webinar: The DPC collaboration gap: why brands struggle to collaborate at scale with their digital assets.* [Webinar]. VibeIQ & Kalypso.

Steenhuis, H. & De Bruijn, E. (2006). High technology revisited: Definition and position. *2006 IEEE International Conference on Management of Innovation and Technology, 2*, 1080-1084. DOI: 10.1109/ICMIT.2006.262389.

Steinert, M. & Leifer, L. (2010). *Scrutinising Gartner's hype cycle approach* [Conference Paper]. Technology Management for Global Economic Growth, Phuket Thailand. https://ieeexplore.ieee.org/abstract/document/5603442

Su, N. & Stolterman, E. (2016). A design approach for authenticity and technology. DIS Conference Paper. DOI: http://dx:doi:org/10:1145/2901790:2901869

Sun, D & Valtas, A. (2016). 3D Printing for Garments Production: An Exploratory Study. Journal of Fashion Technology and Textile Engineering, (4) 3, 1000139. https://doi.org/10.4172/2329-9568.1000139

Sun, L. & Zhao, L. (2017). Envisioning the era of 3D printing: a conceptual model for the fashion industry. Fashion and Textiles. 4(25), pp. 1-16. DOI 10.1186/s40691-017-0110-4

Taplin, I. (2014). Global commodity chains and fast fashion: how the apparel industry continues to re-invent itself. *Competition and Change.* 18(3). p. 246-264. DOI 10.1179/1024529414Z.00000000059

Teyeme, Y., Malengier, B., Tesfaye, T., Vasile, S., & Langenhove, L. (2021). Fit and pressure comfort evaluation on a virtual prototype of a tight-fit cycling shirt. *AUTEX Research Journal.* P. 1-11. DOI 10.2478/aut-2021-0057

The Digital Fashion Group. (2023). On-demanding a phygital reality. *The Interline.* Retrieved https://www.theinterline.com/2023/01/05/phygital-fashion-on-demand/

Townsend, K. & Niedderer, K. (2016). The role of craft in creative innovation: skin, cloth, and metal. In: D. Higgins and V. Dhupa, eds., In this Place: Cumulus Association Biannual International Conference: conference proceedings, School of Art & Design, Nottingham Trent University, Nottingham, 27 April- 1 May 2016. Nottingham Trent University: CADBE, pp. 174-180. Retrieved https://irep.ntu.ac.uk/id/eprint/29330

Tsai, Y. (2020). “In addition to the bags, the new BURBERRY series even has surfboards! The new TB summer monogram series uses CGI computer technology to create a supermodel Kendall Jenner digital avatar.” *Vogue.com Taiwan.* Retrieved https://www.vogue.com.tw/fashion/article/burberry-tb-summer-monogram-kendall-jenner

Turk, R. (2019). Tommy Hilfiger commits to 100 percent 3D apparel design. *Fashion United.* Retrieved from https://fashionunited.uk/news/fashion/tommy-hilfiger-commits-to-100-percent-3d-apparel-design/2019110846123

Van Veldhoven, Z. & Vanthienen, J. (2022). Digital transformation as an interaction-driven perspective between business, society, and technology. *Electron Markets* 32, 629–644 https://doi-org.salford.idm.oclc.org/10.1007/s12525-021-00464-5

Voipio, V., Korpela, J., & Elfvengren, K. (2021). Environmental RFID: measuring the relevance in the fashion industry. 14(3), p.284-292. DOI: 10.1080/17543266.2021.1929510

Viriyasitavat, W., Da Xu, L., Zhuming, B., & Assadaporn, S. (2018). Blockchain-based business process management (BPM) framework for service composition in industry 4.0. *Journal of Intelligent Manufacturing, 31*(7), 1737-1748.

Vogue Business Team. (2020). “Brands eye China’s virtual idols.” *Vogue Business.* Retrieved https://www.voguebusiness.com/technology/china-virtual-influencers?utm_source=Vogue+Business&utm_campaign=975f079248-EMAIL_CAMPAIGN_2020_06_15_08_35&utm_medium=email&utm_term=0_5d1e7914df-975f079248-57829767

Volino, P., Cordier, F., & Magnenat-Thalmann, N. (2004). “From early virtual garment simulation to interactive fashion design.” *Computer-Aided Design.* 37(6), pp. 593-608. https://doi.org/10.1016/j.cad.2004.09.003

Wang, B., Luo, W., Zhang, A., Tian, Z., & LI., Z. (2020). Blockchain-enabled circular supply chain management: a system architecture for fast fashion. *Computers In Industry.* p. 1-4. https://doi.org/10.1016/j.compind.2020.103324

Wang, C., Wang, Y., & Yuen, M. (2002). Feature based 3D garment design through 2D sketches. *Computer-Aided Design.* 35(7). P.659-672. https://doi.org/10.1016/S0010-4485(02)00091-X

Wang, J. (2020, Sept. 14–18). *The Authentic Digital Garment* [Conference presentation]. 2020 3D Tech Festival. Online. https://3dtechfest.com/#2020

Weinswig, D., Schreiner, S., & Fenyo, K. (2022). Digital product creation in retail: understanding the path forward. Coresight Research & Kalypso. https://kalypso.com/dpc-in-retail-research

Williamson, K. (2018). Chapter 16 questionnaires, individual interviews, and focus group interviews (Second edition) in Williamson, & Johanson, G. *Research methods: information, systems, and contexts* (pp 379-403). Elsevier, Chandos Publishing.

Wong, C. (2014). “The role of radio frequency identification (RFID) technologies in the textiles and fashion supply chain: an overview” in *Elsevier Science & Technology.* P.1-12. DOI: 10.1533/9780857098115.1

Wooley, M., Niedderer, K. (2016). “Real or unreal? crafting authenticity in the digital age.” Craft Research. 7(2), pp.159-164. doi: 10.1386/crre.7.2.159_2

World Business Council for Sustainable Development (2011). Collaboration, innovation, transformation. Ideas and inspiration to accelerate sustainable growth- a value chain approach. [PDF] *World Business Council for Sustainable Development* 13 Nov. 2020 Retrieved https://docs.wbcsd.org/2011/12/CollaborationInnovationTransformation.pdf

Yan, H.& Fiorito, S. (2007). “CAD/CAM diffusion and infusion in the US apparel industry.” *Journal of Fashion Marketing and Management.* 11(2), 238-245. DOI 10.1108/13612020710751400

Yap, Y.L. & Yeong W.Y. (2014). Additive manufacture of fashion and jewellery products: a mini review, Virtual and Physical Prototyping, 9:3, 195-201, DOI: 10.1080/17452759.2014.938993

Yotka, S. (2020). “Physical? Digital? Virtual? The masterminds of fashion show production weigh in on runway’s future.” *Vogue.com* Retrieved https://www.vogue.com/article/physical-digital-virtual-what-is-the-future-of-the-fashion-show

Zangue, F., Pirch, C., Klepser, A., & Morlock, S. (2020). Virtual fit vs. physical fit– how well does 3D simulation represent the physical reality. 11th Int. Conference and Exhibition on 3D Body Scanning and Processing Technologies. https://doi.org/10.15221/20.21

Zhang, L., Zhang, H., & Li, Y. (2008). The new development of CAD in clothing. Computer and Information Science. 1(3). P 104-106. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.651.7302&rep=rep1&type=pdf#:~:text=Keywords%3A%20Digital%20clothing%2C%20Artificial%20intelligence,traditional%20manual%20way%20of%20production. Retrieved 23 December 2021.