ABSTRACT

MUSIALAK, ANA LUISA, A. Virtual Prototyping for Textiles: A Case Study Highlighting Real Applications, Benefits and Constraints in a Vertically Integrated Company. (Under the direction of Dr. Lisa P. Chapman and Dr. Marguerite Moore).

The textile industry made a remarkable contribution to revolutionizing production methods in the first industrial revolution. Since then, the textile industry has evolved to mass production, automation, and finally "*the digital era.*" As consumers become accustomed to a fast-paced world, companies must adjust to be time and resource efficient. Textile product development can be as high as 70% of the product life cycle. It consumes not only time but resources, but also substantial physical materials for prototypes. Virtual prototyping has been available for at least 10 years, and despite significant advancements in new software and research showing reduced product development time, there is a still resistance to migrate from physical to digital. What is needed are examples of real-world industry adoption that companies can use as benchmark and adoption map.

A case study focusing on a global, vertically integrated textile and apparel manufacturing company serves as the methodological approach to address the decision process to adopt virtual prototyping, the effect it has in the product development process and workflow, and the advantages and limitations with virtual prototyping including user and manager perspectives. The documentation of the benefits and issues associated with virtual prototyping is an important step to make information available to companies, software developers, and other researchers in the field.

Virtual Prototyping for Textiles: A Case Study Highlighting Real Applications, Benefits and Constraints in a Vertically Integrated Company.

by
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DEDICATION

To the memory of my grandfather Carlos Luiz Alves, the first engineer in the family, who saw this work started but did not live to see it finished. Without your support and beliefs, I would have never made it this far.

BIOGRAPHY

Ana Musialak was born in Brazil. She graduated from Universidade Estadual de Maringa (UEM), Brazil with a Bachelor of Science degree in Textile Engineering. During her undergraduate studies she lived a year in Canada, where she attended Selkirk College and participated in a nanotechnology research group at University of Calgary (UofC). She also spent three months in Mexico, working as an intern in a fashion business startup. After graduating, Ana worked for multinational Nylon and Spandex manufacturers in quality, process, and technical services. As a continuation of her higher education, she joined the Master of Science program in Textile Technology and Management at North Carolina State University (NCSU). As part of her journey at NCSU, Ana worked for two years as a teaching assistant, where she gained experience and taught yarn, fabric and apparel virtual simulation. With her field and academic experience, Ana identified the need to explore virtual prototyping, and focused her research on mapping possibilities and constraints in virtual prototyping for apparel product development.

ACKNOWLEDGEMENTS

I would like to acknowledge the many people that were part of my Master's journey. First, my parents for providing everything I needed to feel confident to pursue my dreams. To my friends and family for unconditional support and love.

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Additionally, I would like to thank interviewees from "Company X" for their contribution and for trusting me with their data. Without them, this research could not be completed.

I would also like to thank Nilit America, for whom I have been interning for the past semester, and for their trust in me and understanding of my time restriction. They always made sure I was prioritizing school and were essential for the completion of my Master's degree.

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CHAPTER I

1. INTRODUCTION

Virtual prototyping (VP) in textiles can start at the yarn level and can be used to also simulate fabric, product and garment fit. At the fabric and garment level, VP enables one to see design, drape, and other physical properties of the textile product. Prototyping is a vital step for textile product development, as this is the most time consuming part of the apparel manufacturing process. Virtualization is changing the way the industry and consumers think, requiring quick responses and high adaptability to changes by significantly reducing the time and materials used for product development, but its implementation still faces some limitations and uncertainties.

1.1 Statement of the problem

Virtual prototyping has emerged as an alternative to help minimizing the time needed for product development or pre-production. Although virtualization has been in use for years, there are still clear challenges to be addressed for full adoption (Jevšnik, 2017; Arribas & Alfaro, 2018; Gill, 2015).

Companies seeking to adopt VP may find limited information as the available information is usually marketed from software companies, isolated from real industry constraints, not accounting for integration with other software and machines, requirement of skilled labor, time, and other technology limitations.

1.2 Purpose of the Study

The textile industry is one of the most impactful to the environment, consuming around 93 billion cubic meters of water, and more carbon footprint than all international

flights and maritime shipping combined (UNCTAD, 2019). During the textile product development, companies work extensively in prototyping, sending physical prototypes back and forth, and consuming time, raw material, and leaving carbon footprint.

In this context, virtual prototyping has been a game changer, making it possible for companies to have an accelerated product development phase and saving resources. Although technology has evolved steeply in the last years, there are some stigmas and constraints in using virtual prototyping. The purpose of the study is to establish a foundational understanding of virtual prototyping (VP) in textile and apparel manufacturing including adoption of VP technology, scope of VP application and advantages and disadvantages of VP practices and software approaches. A case study focusing on a global, vertically integrated textile and apparel manufacturing company serves as the methodological approach for addressing the following objectives:

RO 1. Identify the decision process that the company X undertook to adopt VP process.

RO 2. Examine how different VP technologies are currently being used in company X, and how these processes affect the product development, and workflow.

RO 3. Identify advantages and limitations associated with VP adoption including user and manager perspectives.

1.3 Significance to the field

The research objectives were developed according to the literature review and the need for more real cases of companies using virtual prototyping technologies, and their limitations.

Each RO was listed for specific reasons, and its contribution to researchers and industry.

RO 1. Identify the decision process that the company X undertook to adopt VP process: digital prototyping has been around for over 10 years, but it is not widely adopted across textile manufacturers. Some companies spend a long time in the “decision making” part, and do not have a benchmark or available information to overcome this step. This RO will address this issue.

RO 2. Examine how different VP technologies are currently being used in company X, and how these processes affect the product development, and workflow: current information available about virtual prototyping technologies are by the manufactures of those software and can be extremely limited when looking for a more comprehensive approach, such as implementing in a company with multiple processes linked to the prototype step. This RO will look at a real case using multiple software and how they all integrate with each other and the overall process.

RO 3. Identify advantages and limitations associated with VP adoption including user and manager perspectives: although there are extensive benefits from migrating to digital prototyping, there are also limitations that can be from a business or technical perspective. This objective is important for decision making for companies, but mostly as a guide for future studies and development opportunities in the digital prototyping area.

1.4 Limitations

This case study followed a rigorous methodological path, with a thorough literature review and formal and explicit procedures to elaborate questions and objective. However,

the results were focused on one industry case, and readers should interpret our findings with care, especially when generalizing.

1.5 Ethical Considerations

This study follows Institutional Review Board (IRB) recommendations and procedures. As described on IRB of North Carolina State University's website: "The Institutional Review Board (IRB) protects participant welfare by reviewing research proposals that involve humans to ensure that the planned research activities are ethical in practice and compliant with the federal regulations governing research with human subjects". The required documents from IRB can be found as Appendices to this thesis (NC State Research Administration and Compliance, 2023).

CHAPTER II

2. LITERATURE REVIEW

The traditional prototyping phase of the apparel product development is very time consuming, therefore companies are utilizing different technologies related to virtual prototyping.

2.1 Apparel product development

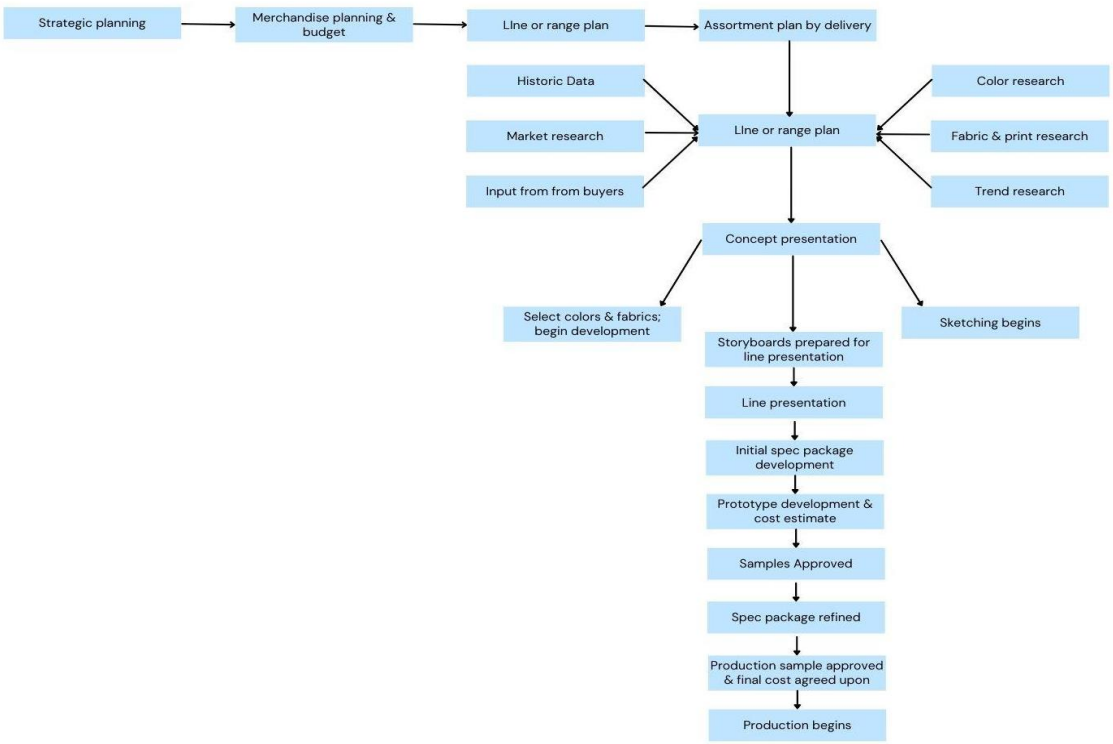
Keiser and Garner (2008) classified the evolution of apparel manufacturing in four stages: craft era, industrialization of apparel industry, advances in mass production, and digital era. The craft era includes anything from the beginnings of textile existence, to around 1846. After that, electric cutting knives and sewing machines were introduced, as well as progressive line assembly and contract system. This stage, called "industrialization of apparel industry" lasted until around the 1960s, transitioning to the "advance in mass production", when automated sewing, numerically controlled cutting, computerized grading and marker-making started being used. The last stage, the one we are currently on, is called *"the digital era*" and started in the 1990s, when body scanning, digital printing, 3D modeling, and texture mapping were introduced. Although the authors considered the digital era to start in 1990, there are constant technological developments, and digitalization is not yet widely used in companies across the globe.

Digitalization is a very impactful resource in textile product development. Product development is the comprehensive approach to everything involved in creating a product, including marketing, design, and sourcing (Keiser, 2022). Apparel product developers are instigated to create, and update styles, to meet customer needs and make them

continuously want it. This system is designed for economic gain, and usually requires fast paced product development process, which can conflict with the creativity process.

The product development stages can vary depending on the final use of the garment. As shown in Figure 1, it is common that design teams present their ideas to partners, merchandising, sales, and marketing teams. When they do that, they must decide on colors, fabrics, designs, graphics, silhouette, and other aspects. At this point, prototypes can be introduced for visualization. Traditional methods include physical prototyping and sampling, which is an iterative method that is very time consuming. (Jefferson & Rowe, 2012) reported that product development time can be as high as 70% of the product lifecycle.

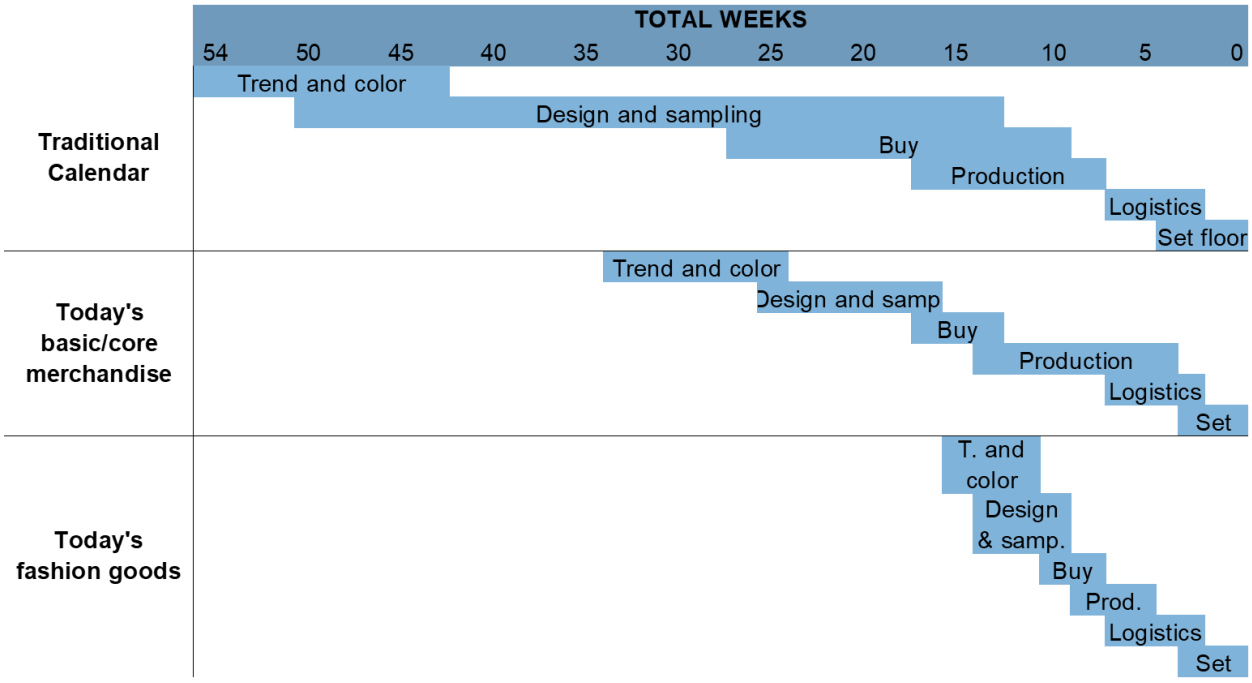
Figure 1. Textile product development flowchart steps commonly followed in traditional industries.



Source: Keiser, 2022.

The traditional product development cycle is 4 to 6 months. This time can increase depending on the type of product, and sourcing conditions. Table 1 shows the estimated product development calendar for distinct types of products: traditional, today's merchandise, and today's fashion goods (Keiser, 2022).

Table 1. Exemplification of three product development timelines



Source: Keiser, 2022.

Over the years the total time to develop products has been shortened due to ease in communication and technologies used in product development. From the calendar on Table 1, we can observe that the time for designing, and sampling decreased significantly from traditional method to nowadays.

2.1.1 Virtual Prototyping in apparel product development

Industries are moving towards digital. It is common to see news about digitalization of objects, workplaces, and services. Recently, we all have become familiar with the concepts of Internet of Things (IoT), 3D, 4D, and 5D movies and experiences, metaverse, and other technologies. In the fashion industry, there were major changes in the last few years in commercialization, with a significant impact from the increased adherence to e-commerce, and social media. However, there are massive developments in the back end of the fashion industry that have not been highlighted for consumers, such as the use of virtual prototypes.

Virtual prototyping has also been referred to by Arribas and Alfaro (2018) as “pre prototyping,” because as for now, most companies will not exclude physical prototypes, but add virtual prototypes as an additional step before that. Including this step allows designers to really capture their ideas, and the concepts are approved or discarded early in the process. In a normal product development flow, the designs would be approved or discarded only after physical samples were made (Arribas & Alfaro, 2018).

The benefit of virtual prototyping is evident throughout the phases of design, product development, manufacturing, and retail. During the design phase, designers can expand their creativity and keep track of the changes, making it easy to make modifications and archive each idea. For product development, 3D prototyping has a significant impact in time, reducing product development time by 20 to 50% when using the right technologies (Papahristou, 2015; Arribas & Alfaro, 2018).

2.2 Current virtual technology for textiles

This section will describe some of the virtual technologies current available in the market for textiles, and academia perspective in these technologies.

2.2.1 Fabrics simulation

The application of fabric simulation can be focused on the fabric properties as well as an only visual approach. To get those results, there are three main techniques for fabric modelling: physical, geometrical or hybrid (Jevšnik, 2017). There are advantages and limitations to each.

The geometrical approach is used with pre-defined fabric characteristics and is very controllable and easy to create computational geometrical models. This model is limited to fabric details, such as wrinkles, and folds. The physical model is based on the properties of the material but can be hard to manipulate and create more visual pieces. The hybrid is a combination of both, which can be a challenge to developers, especially with different fabric structures and flexible materials. There are several parameters to consider in fabric simulation, such as fabric structure, deformation over time, fiber properties, and yarn characteristics (tenacity, elasticity, viscosity, count) (Jevšnik, 2017).

For visual purposes, there are software specialized in woven fabric that provide great assessment of the physical appearance. Penelope is one company, that claims “hyper realistic fabric simulation”. They offer solutions for Dobby and Jacquard fabrics, where the CAD system can be used to design, providing yarn, color and weave libraries, as well as technical data. Figure 2 shows one example of a Penelope developed item (SL., 2023).

Figure 2. Fabric simulation made with Penelope Software

Source: (SL., 2023)

Penelope also offers Computer Aided Manufacturing (CAM) solutions, communicating with productive machines and being able to calculate yarn intake, and other manufacturability data (SL., 2023).

Another example is The DesignScope Company, their software capabilities include simulations for jacquard, and dobby weaves, that provides graphics in composites for highly complex fabrics, that makes it easier for developers to edit the fabric. Additionally, they also provide a module for realistic 3D simulations of fabrics for both weaving and knitting (EAT GmbH, 2023).

2.2.2 Prototyping in knitting

CAD and CAM options for knitting involve highly complex technology since it starts at a yarn level and then simulates the loops and its interactions to create a fabric and/or garment. The use of Machine Learning (ML) and Artificial Intelligence (AI) can address those steps and predict knitted structures, fabrics, garments and even mechanical and comfort properties. More than that, current knit software can predict the quality of knitted

fabrics, including dropped stitches, loops with high yarn tension, yarn rupture points, needle movement, and processing time (Singha et al., 2022; Blaga, 2022)).

Currently, there are some software available for simulations. Shima Seiki's APEX Software is a very complete option, that includes the option to create your own yarn, to pattern design, machine error detection, and garment simulation, including evaluation of fit, drape, and others (SHIMA SEIKI MFG., 2023). Figure 3 shows one example of a garment simulated on the Shima Seiki APEX software.

Figure 3. Knitted garment simulation on Shima Seiki Software

Source: (SHIMA SEIKI MFG., 2023)

2.2.3 Virtual evaluation of thermal comfort

Virtual simulation can also be used to assess thermal comfort in garments. Currently, there is sufficient capability to estimate mechanical behavior and correspondingly drapability of fabrics. For thermal comfort, there are several factors that must be considered for heat and mass transfer evaluation. Simulations that predict air gap thickness and contact area have proven to be realistic. However, there are still limitations

in structural, thermal, and physical properties of the fabrics used for the garments, that consider the yarn type, fabric construction, and other characteristics inherent to the fabric (Güney, 2021).

2.2.4 Apparel virtual prototyping

Apparel virtual prototyping, including 3D simulations, is probably one of the most widely spread virtual technology available for textiles. The technology makes is possible for fashion designers to start their patternmaking in one software, and finish with a visual garment, with sewing, accessories, and fabric simulated in the same program. Some of the software used for this purpose are Browzwear, Clo 3D, Morgan, Style 3D and Optitex. The multiple software available have some of the same fundamental features, such as patternmaking, fabric library, mannequin, fit evaluation, tension maps, and other. However, each of the brands market their features differently. Optitex, for example, markets their precision and efficiency, and their ability to create not only garments but other textile products, such as car seats and furniture upholstery. Clo 3D focuses on the user-friendly aspect of the software, that makes the development process quick and "hassle-free", as mentioned in their website. Morgan advertises as having cutting room leading technology, and focuses on the CAM aspect, being able to facilitate production and automation integrated with CAD. Style 3D highlights the sustainability aspects, and provides all the technical features mentioned for the other software. Besides the technical features, they offer enterprise solutions, such as features for eCommerce B2B/B2C, Lookbooks, VR Showrooms, and NFTs. Additionally, Style 3D offers digital Bill of Materials (BOM), accounting for all the material used even before production. (Morgan

Tecnica, 2023; Browzwear Solutions Pte Ltd., 2023; CLO Virtual Fashion LLC, 2023; Optitex, 2023; LINCTEX, 2023).

2.2.5 Virtual assessment of fit

When prototyping garments, there is the possibility to fit in virtual mannequins. All the software mentioned for apparel virtual prototyping provide means of visualizing garment fit, usually with tension maps representing the distance between body and garment. The tension maps can be done by inputting fabric information, or by creating points in the garment and correlating with the virtual body (Gill, 2015) .

Min-Jeong Lee (2011), found that bending strength, buckling point, density, particle distance, and shear are parameters that can be compared from physical and virtual prototypes.

2.3 Limitations with virtual prototyping and future of textile product development

Although virtual visualization of garments has made huge progress over the last few years, and has been adopted in many companies, there are still limitations to fabric simulations. Current virtual development of fabrics is insufficient. Most simulations use the geometrical model, which is great for the appearance of the product but will not reflect the mechanical and physical properties of the fabric (Jevšnik et al., 2014) .

In simulation of thermal comfort evaluation, as mentioned previously, there are still limitations in structural, thermal, and physical properties of the fabrics used for the garments, that consider the yarn type, fabric construction, and other characteristics inherent to the fabric (Güney, 2021).

Another limitation linked to virtualization is the labor. Although it opens space for other professions to work in textiles, such as programmers, 3D designers, and engineers, as it is right now it requires that these professionals have advanced understanding in textiles. The combination of these skillsets, creates a labor issue in the initial phases of VP implementation (Gill, 2015) .

CHAPTER III

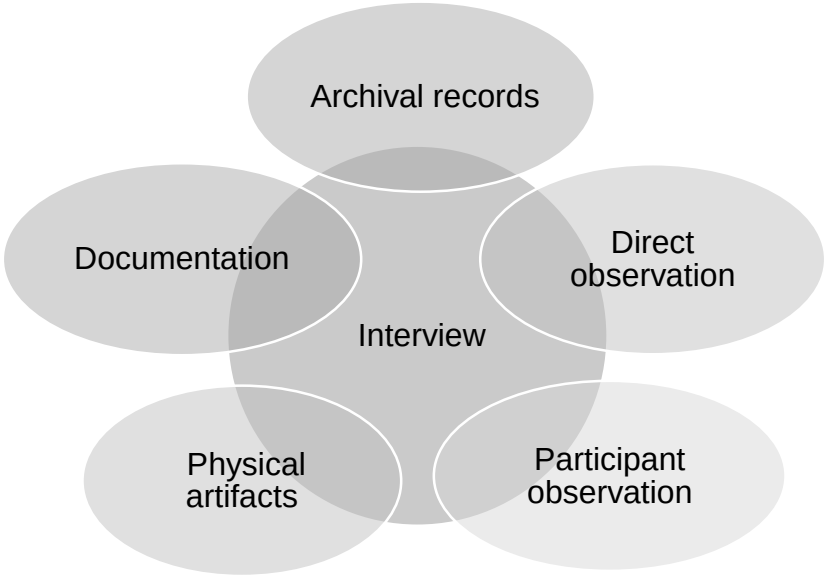
3. RESEARCH METHODOLOGY

Yin (2014) states the importance of case studies to address “how”, and “why” questions with a rigorous method. According to literature, there are not enough holistic studies in companies using VP (Jevšnik, 2017). The bulk of papers published about VP are experimental, by testing VP in multiple different setting and for different end uses as seen in Gill, S. (2015), Güney, S. (2021), Min-Jeong Lee, H.-S. S.J.(2011), and Papahristou, E (2015).

3.1 Sources of evidence

Yin (2014) lists six main sources of evidence in case study research: documentation, archival records, interviews, direct observations, participant-observation, and physical artifacts. This case study will consist in a combination of the six sources, as described below.

Figure 4. Sources of evidence in a case study research



3.1.1 Interview

The interview was the main source of information. Interviews were performed with experts in the field, such as product developers, and other textile industry professionals. The benefits from the interview are providing targeted information, focused strictly on the ROs, and how insightful the interview can be, by getting personal views from experts.

3.1.2 Documentation

Documentation supported the interview, by providing exact numbers, dates, and names. The documentation is an important, and stable source that is always available for cross reference, and to legitimate the information from the interview, eliminating bias.

3.1.3 Archival records

If available, archival records will also serve as cross reference, and can be a reliable source of historical data about the company, and the use of virtual prototypes.

3.1.4 Direct observation

Observation is an important source for a holistic view that adds to the interview by understanding the social, and cultural aspect involved with the specific company and the current scenario on the textile industry.

3.1.5 Participant observation

Derived from the interview, this is a crucial step to identify the participant motives, and perception about the topic. This source of evidence is extremely relevant for the analysis and interpretation of the data. The participant observation and the documentation together, can distinguish the data from precise against biased.

3.1.6 Physical artifacts

Physical artifacts are crucial for the comparison between the physical and digital version of the products, and will be incorporated on the results.

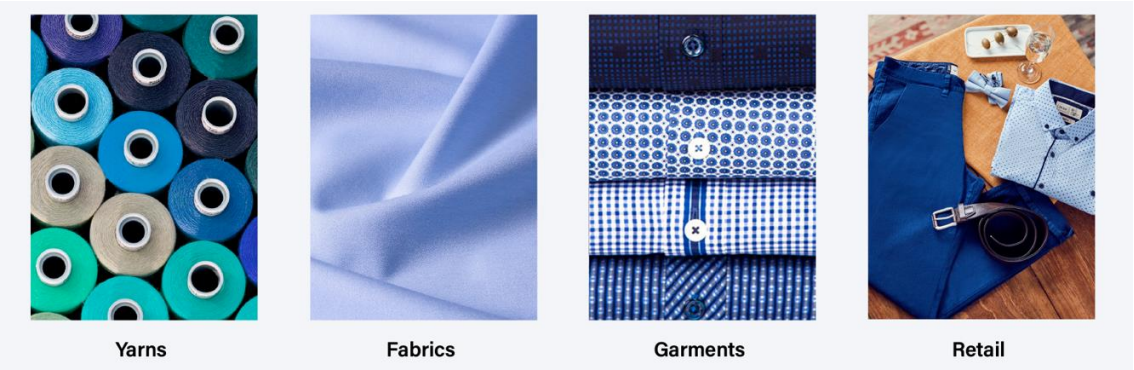
3.2 Procedure

Considering the ROs, and the sources of evidence mentioned, the procedure of this research was the following:

3.2.1 Company selection

Company X was selected for being a multinational company, well known for being a pioneer in technology and automation in the textile field. The company operates vertically in the textile business, starting from yarn production, all the way to apparel production. Figure 5 illustrates the different products made by Company X.

Figure 5. Company X's processes



Source: Company X

The expert panel is a selection of professionals at company X. To include business, as well as software user's perspective, professionals from managerial and product development areas were selected.

3.3.2 Expert panel interview

Each interview question was designed according to the ROs. The expert panel consisted of a designer and a technical director, to obtain both, technical and managerial perspectives. Table 2 correlates each question to its RO. The interview questions and protocol can be found in Appendix A and B, respectively. The recruitment email is Appendix C. Consent form approved by IRB is Appendix D.

Table 2. Research objective and its corresponding interview questions.

Research Objective	Questions
RO 1	Q11, Q13, Q14.
RO 2	Q1, Q2, Q7, Q8, Q9, Q10.
RO 3	Q3, Q4, Q5, Q6, Q12.

3.3.3 Selection of additional sources

The interview will be the main source of evidence, but as part of the methodology, there will also be a visit to Company X, where the other sources of evidence will be also collected. Table 3 correlates the ROs with the expected sources of evidence to be combined with the interview.

Table 3. Research objective and its corresponding sources of evidence

Research Objective	Sources of evidence
RO 1	Archival records, documentation, and participant observation.
RO2	Physical artifacts.
RO3	Participant observation, and documentation.

3.3.4 Data analysis and conclusion

The data analysis will be organized by RO and validated from the combined sources of evidence. Data triangulation will be applied to corroborate the information provided by differences sources, cross checking the information.

CHAPTER IV

4. RESULTS AND FINDINGS

An analysis of the data collected through various methods revealed findings within the research data scope. The observation, interview, and documentation data were grouped under each Research Objective (RO), according to the methodology.

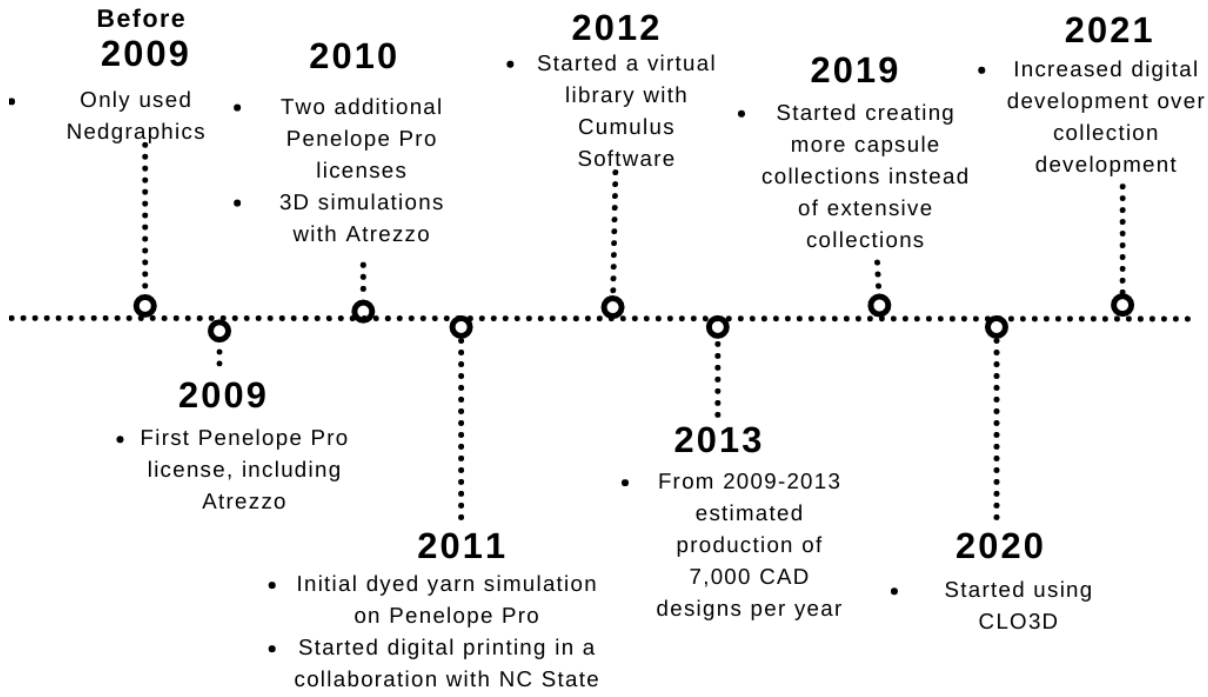
4.1 Research Objective 1

The purpose of Research Objective (RO 1) is to “Identify the decision process that the company X undertook to adopt VP process.” This objective was addressed using data from two sources: documentation and interview questions. The interview questions that address this objective are represented by Q11, Q13, and Q14 on the protocol.

The company’s Technical Director (TD) and Designer served as expert respondents to provide insight into RO 1. Note that the TD expert informant has a long reputation as a leader in the global textile field and is therefore very knowledgeable of innovation adoption in the industry in recent decades. The TD clearly expressed enthusiasm and openness toward innovative technologies in the industry. The TD was present in Company X from the initial adoption of VP.

The interview explored the adoption timeline by focusing on specific points that the company decided to move forward with VP as well as documentation of the specific timeline (Figure 5). The TD reported that Company X first adopted VP technology in 2010, and has continued to build capabilities in this area since this time adding resources to their product development since then. Some examples are added licenses to their original Penelope Pro purchase, and adoption of a virtual library.

Figure 6. Timeline of technology adoption at Company X



Question 14 addressed the motivation(s) for company X to initiate VP. As described before, Company X represents a relatively large company in the industry, and for years has been known for its commitment to innovation. The TD interview responses suggest that the original stimulus for making the change to VP did not arise from an internal idea, but rather a requirement for serving customers. In 2010, brands and retailers began to demand the VP capability from Company X, therefore the company adapted to this preference. The TD also observed that customer (i.e., brand) demand for VP capability coincided with their transition toward outsourcing product development. As a result, Company X as a fabric and garment manufacturer was forced to build a product development department capable of internally creating collections that address consumer preferences and market trends.

According to the TD, in 2020, an additional influential factor was the COVID-19 pandemic. The traditional methods to communicate with customers, such as trade shows and travelling were rendered impossible at the time. Further, foreknowledge regarding the ability to resume pre-pandemic behaviors was unknown. Therefore, this situation demanded company X to rapidly deploy VP technology (i.e. virtual showroom) to conduct business in a constrained environment.

Question 11 sought to identify the potential barriers company X encountered when adopting digital prototyping. The respondents suggested to different categories of barriers in their responses including: technical challenges, and managerial and sales challenges. They suggested that color matching poses a persistent technical barrier when using VP technology. The respondents described that the propensity for virtual products to appear differently to users with different screen types or settings. There was a learning stage to understand how to calibrate the color to match their physical samples. From the sales and customer services point of view, there is a barrier in the acceptance of product development and purchasing teams. The customers have to trust the company, and understand the benefits, that from company X perspective are clear, such as being cheaper, faster, and more sustainable.

Lastly, when integrating VP, the respondents indicate that there is a lack of skilled workers who understand these technologies in the labor market. The designer at company X expressed an interest to learn the technology, therefore the company invested in training to aid her development. The designer further suggested that VP is very time consuming, claiming that development of a virtual catwalk on Clo3D requires about 20 hours. However, the designer noted that her proficiency with Clo3D is somewhat limited.

4.2 Research Objective 2

Research Objective 2 (RO 2) is to “Examine how different VP technologies are currently being used in Company X, and how these processes affect the product development, and workflow.” The interview questions designed to address RO2 include: were Q1, Q2, Q7, Q8, Q9, and Q10.

Q1 asked about the different stages of product development where Company X is engaged in prototyping, and Q2 asked which software they use for each step. Q1 and Q2 were divided in 5 sections (a, b, c, d, and e), considering the different process they have as a vertically integrated company.

Table 4 summarizes the answers for Q1 and Q2.

Table 4. Application of VP in different stages of product development

	Yarn	**Fabric**	**Product**	**Fit**	**Manufacturing**
Q1. At what points of the product development process are you prototyping?	Yes	Yes	Yes	No	No
Q2. What software do you use for each step?	Amsler, Penelope	Penelope	Penelope, Clo 3D	N/A	N/A

The full answers combined for Q1, and Q2, are reported below.

a. Yarn. There are two software that Company X can use for prototyping, one is Amsler, and the other is Penelope. Amsler is rarely used, but they can simulate slubs, twisted and mouline yarns, and then apply it to simulate knitted fabrics. However, Penelope is the software they use in a regular basis, where they can edit yarns to simulate their fabrics.
b. Fabric. They simulate fabric using the Penelope software. The company's simulated fabrics will go to their virtual showroom, digital library, printed and sent to customers, and sometimes uploaded into other platforms.
c. Product. They sell yarn, fabric, and garment as final product. As yarn and fabric were mentioned before, the product here will be referred to as garments. The garments are simulated with Clo3D or Lectra for specific customers, they do not have a library or virtual display for garment simulations.
d. Fit. Company X does not use fit evaluation for their garment production or as part of the communication with the customer. Although the software they use for garment simulation (Clo3D) has the capability to evaluate fit, it is still an area to be explored by the company.
e. Manufacturing. Currently Company X is not working with prototypes to determine manufacturability. They do risk maps for articles that might be hard to manufacture, but in traditional ways, by making samples and by experience but do not use VP for this stage.

Question 7 asked "How do you use digital prototypes?", giving 6 categories:

a. Internal aesthetic assessment.
b. External aesthetic assessment.
c. To assess fit.
d. To determine cost and/or time.
e. To determine manufacturability.
f. Other.

Company X reported to use mainly for options a, and b, which are respectively, internal and external aesthetic assessment. For fabrics, they use virtual prototypes to simulate colors, patterns, and texture and show the customers in the most realistic way. For garments, they can also evaluate it internally, which accounts for the other side of the fabric, and it is also an important feature.

For manufacturability, and determining cost and time, Company X is exploring other AI options to integrate with the design software, and digital library, but currently it is not being used.

Question 8 asked about technologies used to support digital prototyping. The answers are separated by categories below.

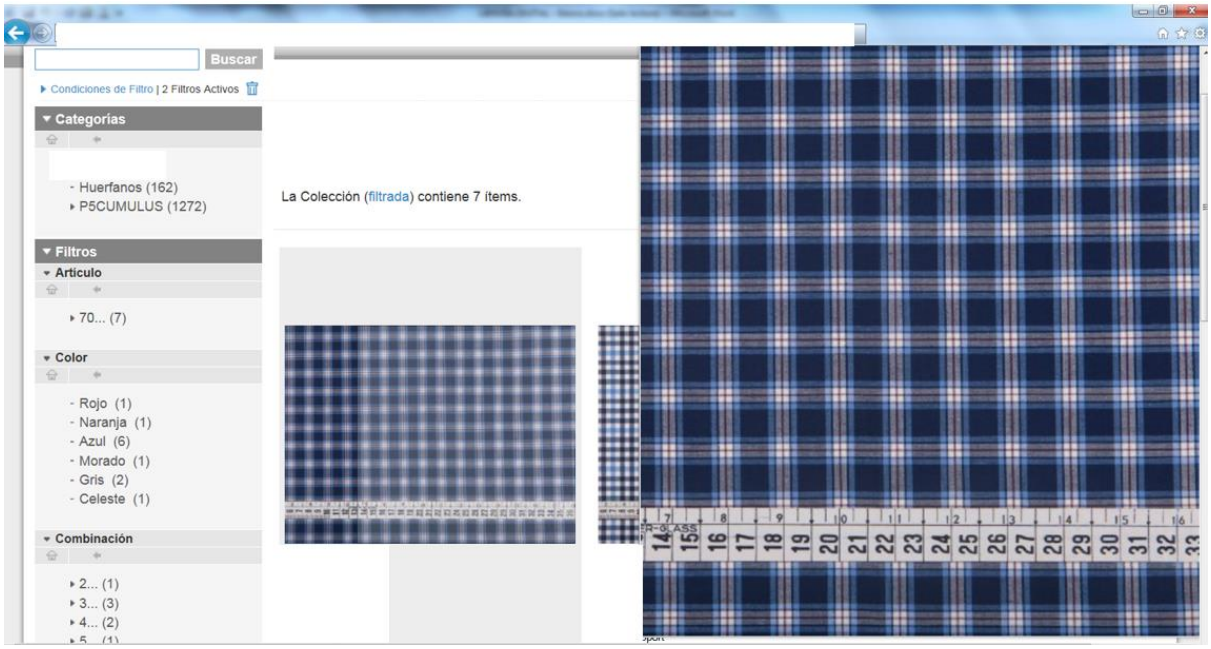
a. CAD. The CAD technology is the core of digital prototyping, and it is used in various steps as mentioned before. The CAD software are Amsler, Penelope, Lectra, clo3D, Adobe programs, and Nedgraphics.
b. Scanning/photography. Scanning and photography are important tools to support CAD. One example is when one fabric is physically developed and they scan/photograph to simulate in other colors. Another example is when the

company wants to add fabrics to their virtual showroom, they can photograph the fabric with the drape, and also scan it.

c. Digital libraries. Company X has digital libraries, and also a virtual showroom. Digital library is their internal library of fabrics, and virtual showroom is the customer's library. From the customer's showroom, it is possible to see the fabric in real scale, simulate in garments, check essential information about the fabric, such as width, and weight, and place orders from the same platform.
d. Color Management systems. Company X uses Datacolor spectrophotometer, but it is not integrated to the CAD software.
e. Other. AL Showroom, atrezzo, digital textures.

According to the Designer in company X, the showroom is one of the great benefits of virtual prototyping. The program Atrezzo provides a powerful tool that allows customers with access to a virtual library where they can see the available fabrics, customize colors, see the pattern scaled in a garment, and place orders straight from the same website. The library provides physical information for the fabric, such as width, weight, and fiber content. The designer also mentioned that they have a digital swatch book, that can be sent by email, WhatsApp, or preferred communication channel, if the customers desire to do it that way. Figure 6 shows a screenshot of the fabric virtual library used by Company X, where they can check different colorways and scale.

Figure 7. Fabric virtual library



Source: Company X

The garment simulations are not part of the Company X main VP workflow. Company X's focus is in fabric simulations, for the virtual showroom and swatch books. However, the company uses Clo3D to simulate their fabrics in garments for presentations, and for specific customers. Company X also operates a separate division for its garment brands, with a dedicated product development team, which also uses VP.

Question 9 asked for examples of Company X's digital prototyping process. The workflow can vary per product or customer. Usually, on a fabric collection development, Company X develops their fabric collection in the following order:

1. Dye knitted fabric to develop the color palette.
2. Recreate the color digitally. Color palette is printed and compared with the original dyed yarn or knitted fabric sample.
3. Create the VP fabric, to be used on the virtual showroom or catalog.

4. If fabric is requested, the physical version of the fabric is created.

Additional evidence for this question was obtained through physical artifacts provided by Company X. Figure 6 shows the original knitted fabric and yarn dyed sample on the left, developed to create the colors physically, and on the right side the color virtually created to match the physical samples.

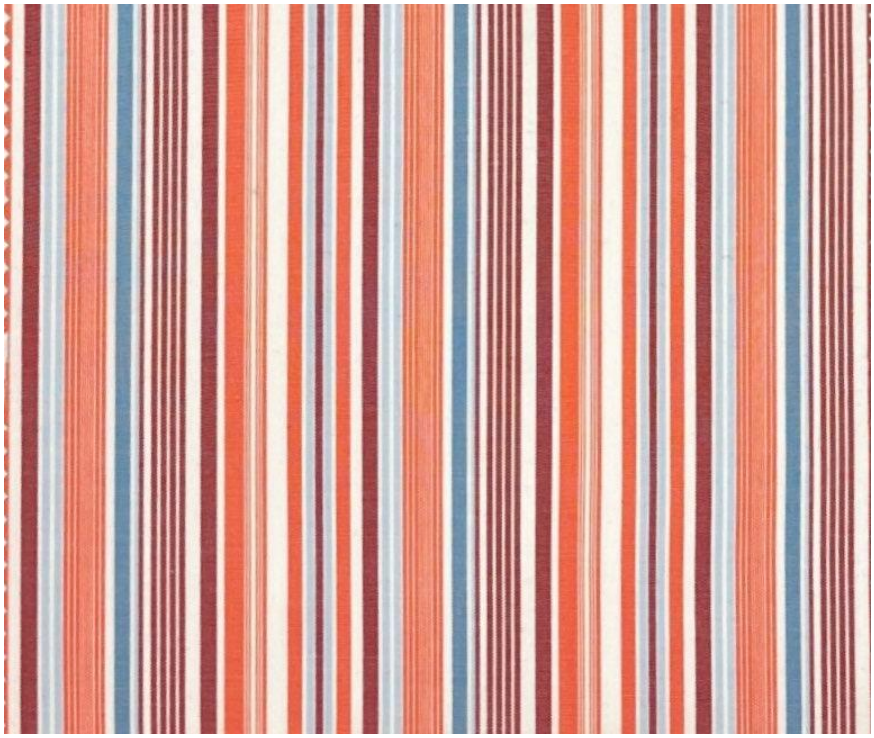
Figure 8. Knitting sample and paper printed sample for color development

Figure 7 is the virtual simulation of the fabric, created on Penelope software, using the color development mentioned for Figure 6.

Figure 9. Fabric virtual prototype

Figure 8 is the physical fabric created after the digital version was approved and requested to be produced.

Figure 10. Physical fabric



Another workflow they can use VP on is by creating the physical fabric and then recreating it virtually in other colorways. This is a very effective method when the physical version is required, or when the company needs to develop a completely new fabric and wants to test the technology to make it physically. After they have one sample, they use prototypes to simulate other colorways, and save time and resources. Figure 9 is the fabric produced physically and Figure 10 is the simulation in multiple colorways.

Figure 11. Physical fabric example

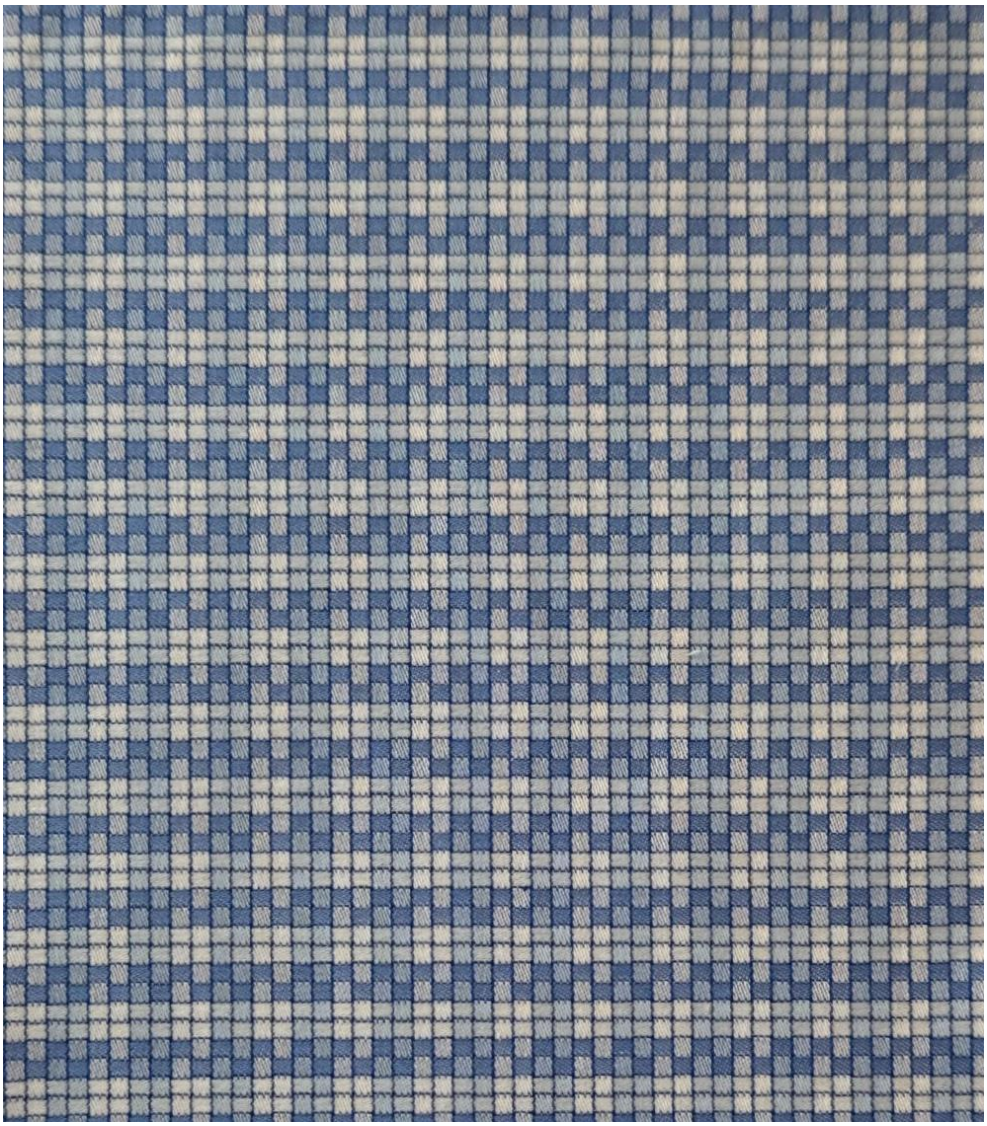
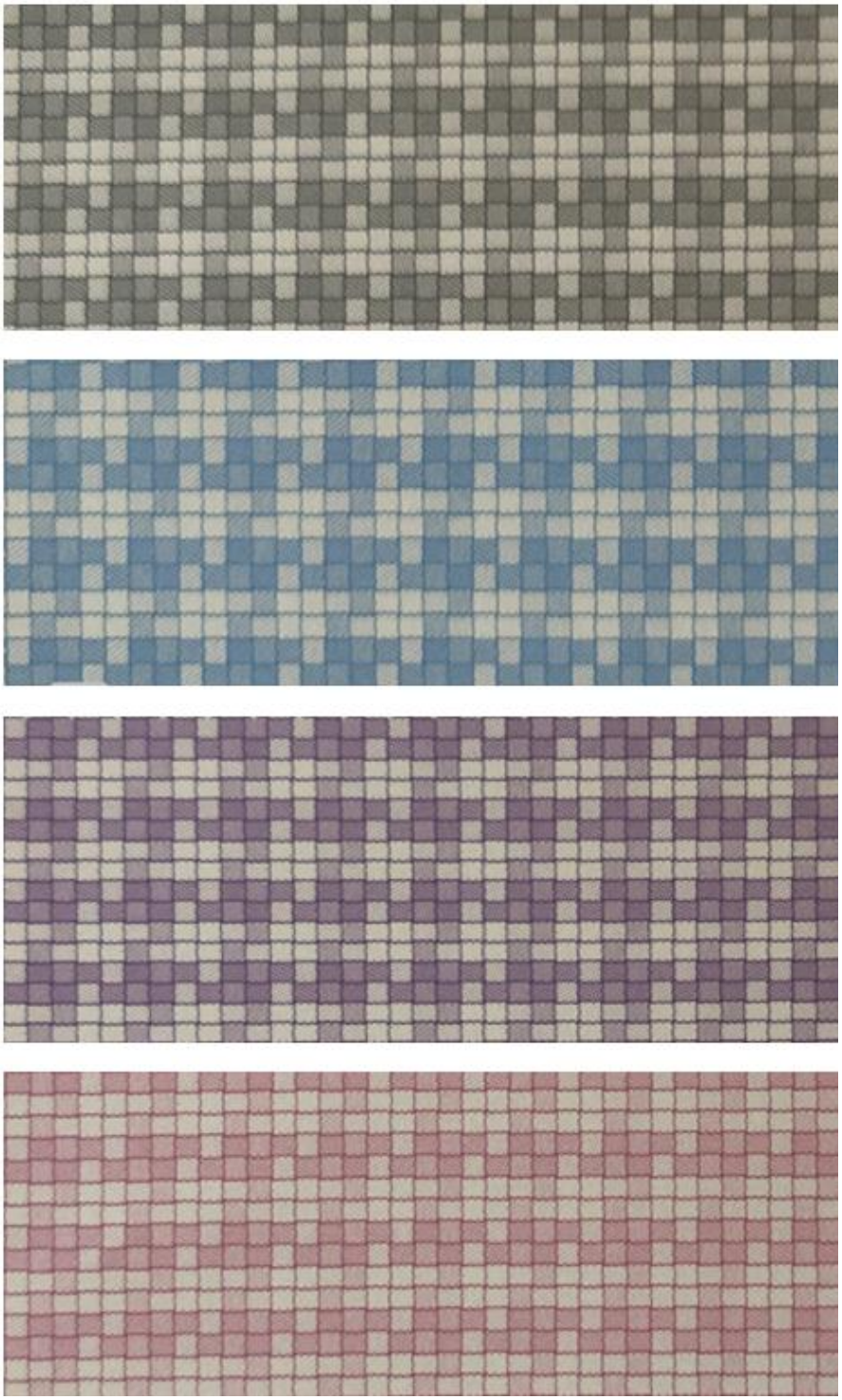


Figure 12. Fabric simulations in multiple colorways



Additionaly to the workflows presented, company X also makes garment simulations according to customers' needs. Figure X is an example of a shirt made at Company X.

Figure 13. Virtual prototype of a shirt

Question 10 asked what type of standards Company X use or follow for digital prototyping. They reported to use Pantone for color specification, and although Company X has a full textile testing laboratory under AATCC and ASTM standards, the evaluation of VP is only visual. The visual evaluation is performed by the designer itself, and approved by the commercial team before getting to customers.

4.3 Research Objective 3

Research Objective 3 (RO 3) seeks to "Identify advantages and limitations associated with VP adoption including user and manager perspectives." The questions designed to fulfill this research objective were Q3, Q4, Q5, Q6, and Q12. Question 3 asked about cost savings when digital prototyping and the percentage they expect to save

annually. Although the technical director (TD) of Company X did not have a total or percentage of yearly savings, he reported significant cost savings. Cost savings can arise from labor, physical swatch book production, shipping of physical samples, ability to respond promptly to customer, and flexibility to communicate with customers anywhere, getting information quicker, and having a competitive advantage over other suppliers. Additionally, when physical samples are made, there are numerous associated processes including: color development, frames and cylinders engraving for printing, setting up warps, and validating all these processes.

To elucidate this question, the TD provided an example by pointing out with the number of physical swatch books they used to make for each new collection. Before using VP, the company would produce around 200 swatchbooks that were shipped to customers, requiring labor to make the fabric samples, the swatch book, and arrange the shipment. Additionally, there would be added shipping costs as well as carbon emissions. Nowadays, the company makes around 20-25 books, corresponding to 10.0%- 12.5% of the previous number. The swatch books are sent to few companies that still require the physical versions, and they are also used in textile expositions, as the company observed it was important to also have physical swatchbooks on these occasions.

Additionally, as part of documentation, Company X provided cost estimates for physical and virtual prototyping. The cost analysis was made for three fabrics, including yarn cost, labor, additional materials and dyeing. Figure 11 presents a picture of Sample 1 analyzed, which is a 100% pima cotton fabric, with dyed yarn Ne 60/1 on weft and warp.

Figure 14. Sample 1 for cost analysis

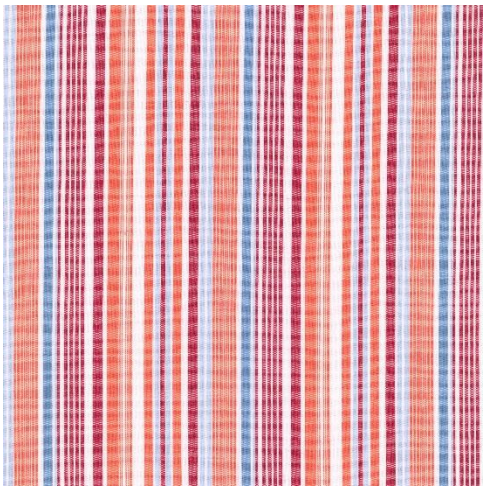


Figure 12 is a picture of Sample 2, which is a 100% pima cotton fabric, with dyed yarn Ne 60/1 on weft and warp but with a different pattern.

Figure 15. Sample 2 for cost analysis

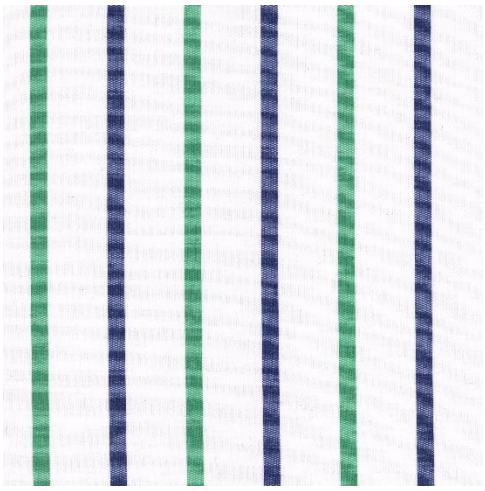
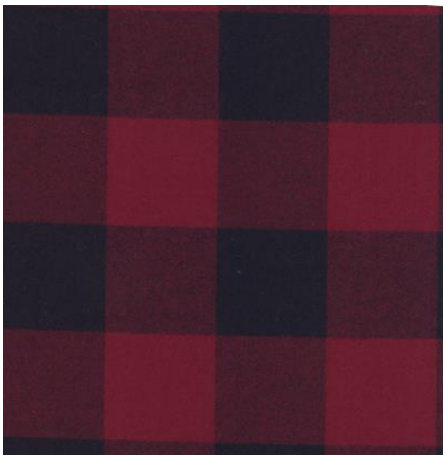


Figure 13 is a picture of Sample 3, which is a 100% upland cotton fabric, with dyed yarn Ne 40/1 on weft and warp.

Figure 16. Sample 3 for cost analysis



The cost estimate for sample 1 is shown in Table 5.

Table 5. Sample 1 cost breakdown for physical and virtual sample

		HANDLOOM	Total (USD)	CAD	Total (USD)
Yarn	Consumption (kg)	1.0	20.0	0.0	0.0
	Cost (USD/kg)	20.0		0.0	
Pre-production process	Direct hours of labor	22.4	37.8	6.0	23.6
	Cost (USD/hour)	1.7		3.9	
	Indirect hours of labor	0.9	3.5	0.0	0.0
	Cost (USD/hour)	3.9		0.0	
	Additional materials	2.0	2.0	0.0	0.0
Dyeing process	Average cost (USD)	0.3	0.5	0.0	0.0
	Sample factor	2.0		0.0	
		TOTAL (USD)	**63.8**	**TOTAL (USD)**	**23.6**

Table 6. Sample 2 cost breakdown for physical and virtual sample

		HANDLOOM	Total (USD)	CAD	Total (USD)
Yarn	Consumption (kg)	1.0	20.0	0.0	0.0
	Cost (USD/kg)	20.0		0.0	
Pre-production process	Direct hours of labor	22.4	37.8	6.0	23.6
	Cost (USD/hour)	1.7		3.9	
	Indirect hours of labor	0.9	3.5	0.0	0.0
	Cost (USD/hour)	3.9		0.0	
	Additional materials	2.0	2.0	0.0	0.0
Dyeing process	Average cost (USD)	0.3	0.5	0.0	0.0
	Sample factor	2.0		0.0	
		TOTAL (USD)	**63.8**	**TOTAL (USD)**	**23.6**

Table 7. Sample 3 cost breakdown for physical and virtual sample

		HANDLOOM	Total (USD)	CAD	Total (USD)
Yarn	Consumption (kg)	1.0	11.0	0.0	0.0
	Cost (USD/kg)	11.0		0.0	
Pre-production process	Direct hours of labor	22.4	37.8	6.0	23.6
	Cost (USD/hour)	1.7		3.9	
	Indirect hours of labor	0.9	3.5	0.0	0.0
	Cost (USD/hour)	3.9		0.0	
	Additional materials	2.0	2.0	0.0	0.0
Dyeing process	Average cost (USD)	0.5	1.0	0.0	0.0
	Sample factor	2.0		0.0	
		TOTAL (USD)	**55.3**	**TOTAL (USD)**	**23.6**

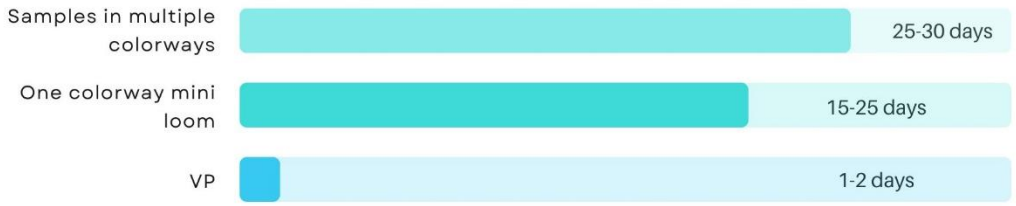
Table 8. Summary of cost comparison between Handloom and CAD prototyping

Total cost summary (USD)	HANDLOOM	CAD	Cost savings (%)
Sample 1	$63.83	$23.65	63%
Sample 2	$63.83	$23.65	63%
Sample 3	$55.33	$23.65	57%

As an addition to Q3, Q4 asked about time savings encountered when digital prototyping. The answer from the TD from the previous question suggests evidence of time savings from using VP. However, more evidences where collected from documentation, and observation. From documentation, it was possible to compare the time required to produce physical samples. Figure 14 presents the time requirements for the product development team to produce samples in three different ways. The first is by producing a physical fabric in multiple colorways, by using an automated warper. The

second is by manually threading the warp yarns, and making a physical sample in only one colorway using a sampling loom (Evergreen II, 8 colors, 500mm width, approximately 2,000 ends). The third is by creating CAD VP.

Figure 17. Time required to make fabric prototypes by different methods



We can observe from the three methods, that digitally prototyping is significantly faster. However, the current process flow for some customers or products continues to require physical samples. Company X works by simulating what they can, and that includes combining methods. For example, they can create a physical fabric for one colorway, and then simulate the other colorways.

To complement this question with observational data collected during the factory visit, the researcher observed the intensive labor procees required to thread the warp yarns for the samples made on sampling looms, which in production this step is automated. The looms used for samples are threaded manually, and require two full time employees threading it. It is important to highlight that to do that, employees have to be qualified, with no vision restrictions, have attention to detail, and agility.

Question 5 asked if the company believed that digital prototyping is more sustainable than physical prototyping. The TD strongly agreed that VP is more sustainable than physical prototyping. Examples of the sustainability advantages afforded through VP use provided by the TD include:

- The reduction in the number of physical swatch books produced and associated reduction in carbon emissions from shipping these swatchbooks worldwide.
- The reduction in use of dyed yarn stock to produce fabric swatches with conserves resources and reduced costs for Company X.

Question 6 asked about additional advantages found in VP. The TD cited assessing the fabric appearance in an early stage and being able to communicate faster with customers as being the greatest benefit of VP. Finally, question 12 asks if there is any process in which VP is considered inefficient. According to the TD, VP is beneficial when replacing physical prototyping. However, some customers will refuse only virtual, and request the physical version, or both. In these cases, VP is adding another step to the product development flow, which ultimately increases cost, and time.

From a technical point of view, there are limitations and potential improvements that need to be addressed. For example, Company X compares physical samples only with the printed version of the developed VP. That is due to the different types of screens and lights, that can change the colors significantly from one user to the other. When printing in paper, some colors and finishing effects are hard to be achieved. Figure 15 shows one example of a dark color that when printed does not look exactly as expected. Figure 16 is a picture of the fabric in the right colorway. Although this is one challenge faced by Company X, they found a way around it and still make it possible to VP by including a sample of the physical yarn used in the right color, as seen in Figure 15.

Figure 18. Fabric simulation out of color specifications

Figure 19. Physical fabric in the right color

CHAPTER V

5. FINAL ANALYSIS (DISCUSSION)

Textile product development is an extensive process that requires specialized labor, is time consuming, and expensive. Traditional product development is shifting to virtual, and making the process significantly faster and more sustainable. This section will discuss the case reported by Company X when adopting this technology.

5.1 Discussion

5.1.1 Research Objective 1

RO 1 is “Identify the decision process that company X undertook to adopt VP process.” As described in the results, there were major scenarios observed in the market that made the shift to VP happen. The major turning points were 2010, and 2020. These shifts were linked to the change in the brands business structure (i.e., changing product development requirements among brands), and the pandemic, respectively.

The timeline (Figure 14) illustrates that although there were major changes in 2010 and 2020, by starting to use 3D simulations on Penelope and Clo3D, respectively, there were many other events that influenced technology changes throughout the past 14 years. The timeline demonstrates that VP integration requires a long term vision with a commitment of time and capital investment. The results from the interview indicate that the adoption of VP was impacted by global events that were not linked specifically to company X. However, the participant and direct observation provide an important insight into understanding why Company X grew under those circumstances while other companies in the same field and same conditions did not develop at the same rate.

1. The first factor that can be associated with the company's development is the attitude and vision of the staff. The TD is known in the textile business for actively participating in innovation events and having a great network globally. The TD is also constantly investing in education, and working with universities to advance in technology. Therefore, the adoption of leading technology for company X can be linked to the avid managerial interest.

2. The second factor that should be accounted for is the nature of Company X. Company X is a vertical textile industry, with customers in multiple countries, that goes back to the country they are located and trade agreements in place. The globalized market that Company X serves is one major component of the reason why Company X "had to shift" to VP, as described by the TD. Smaller companies, or same sized local companies would probably have a delay to feel the need to adopt VP. The same applies to companies located in other countries, or in other conditions, where this "need" could be less urgent as perceived by Company X.

5.1.2 Research Objective 2

RO 2 is "Examine how different VP technologies are currently being used in company X, and how these processes affect the product development, and workflow." The results show that Company X use multiple CAD systems, and other linked technology, such as virtual showrooms and digital swatch books.

As mentioned, Company X is dedicated to technology investment which is evidenced by their observed software selection. Currently, they have state of the art technologies to generate advanced prototypes and simulations. However, due to implementation and

market needs, they use what is viable, and work in implementing additional tools in the future, such as fit evaluation and manufacturability analysis from prototypes.

The workflows and applications of the use of VP by Company X are a valuable resource for researchers, companies, and developers trying to understand the applicability of specific software for VP in general, and how to integrate the technology in the current process. The company began with a single technology 13 years ago and continues to integrate new technology to adapt to market needs.

5.1.3 Research Objective 3

RO 3 is “Identify advantages and limitations associated with VP adoption including user and manager perspectives.” The interview questions for this RO focused on time savings, cost savings, sustainability, and additional advantages and limitations of VP. The results provide evidence of both time and cost savings, as well as benefits to the environment when using VP. Cost wise, VP costs 37%-43% of what physical samples cost. With an estimated production of 7000 CAD designs a year, and $31.68 to $40.18 dollars’ difference in cost per prototype, the company would be saving from $221,760 to $281,400 a year if 100% of the prototypes were made digitally. However, as seen previously, sometimes the physical will also be done after the VP. Therefore, Table 9 shows cost savings when 100% is VP and no physical sample needed, followed by 75% only VP and 25% VP and physical sample required, 50% only VP and 50% VP followed by physical, and lastly, when all the VP are also made physically. The cost for table one was based on sample 1, shown in Figure 11 and Table 5.

Table 9. Cost savings based on VP usage with or without adding physical samples

	Percentage	Physical sample cost	Virtual sample cost	Cost/7000CAD	Total Savings/year
VP	100%	$ 63.83	$ 23.65	$ 165,550.00	$281,260.00
VP+ Physical	0%	$ 63.83	$ 23.65	$ -	
VP	75%	$ 63.83	$ 23.65	$ 124,162.50	$169,557.50
VP+ Physical	25%	$ 63.83	$ 23.65	$ 153,090.00	
VP	50%	$ 63.83	$ 23.65	$ 82,775.00	$57,855.00
VP+ Physical	50%	$ 63.83	$ 23.65	$ 306,180.00	
VP	0%	$ 63.83	$ 23.65	$ -	($165,550.00)
VP+ Physical	100%	$ 63.83	$ 23.65	$ 612,360.00	

Another consideration from the cost analysis is the impact of materials and labor in making prototypes. The physical samples have the added cost of material that virtual does not have. However, VP requires specialized labor with a higher rate per hour. That is especially relevant when compared to other countries, with different wage rates and delta between skilled and unskilled labor.

As it is Company X's nature to adapt, it was difficult for the interviewees to come up with challenges faced when virtual prototyping. That is because the processes they have implemented were achieved by trying and fixing, until they got to a solution, as the example of the unachievable color in simulation where they still used VP but added physical dyed yarns to cover the color issue.

5.2 Recommendations for Future Research

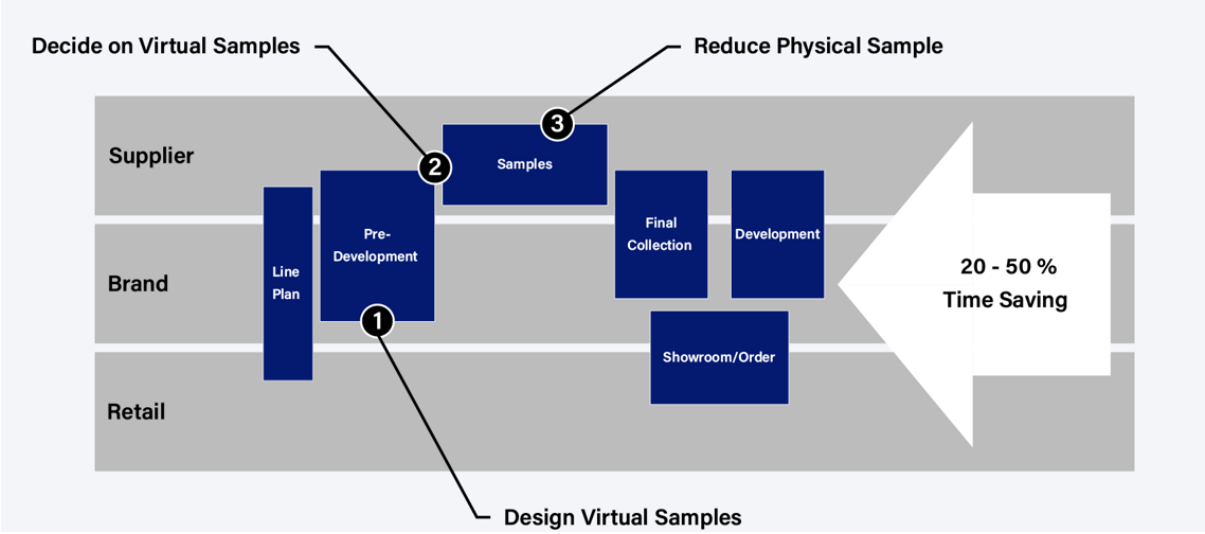
Based on the results of the study, there are several recommendations for future research. First, the same format of case study could be applied to other areas of textile companies, such as knitting, or manufacturers that only produce garments, identifying the possibilities and constraints with associated VP technologies. Secondly, noting the resistance mentioned from company X for some of their retail customers to accept VP, it

would be interesting to have case studies that provide the brands' perspective and the challenges/advantages faced. Finally, this study took a holistic, broad approach when documenting how a company can implement VP. Some of the research findings demonstrated the reduction in cost and time of fabric product development through interviews, observation and collection of artifacts. What could be helpful are studies solely focused on these two single aspects from multiple cases. Cost is usually the determinant factor for business to adopt certain technologies, and time is costly.

5.3 Conclusion

The case study on company X accomplished its objectives by firstly, identifying the process followed by a company to adopt VP, which accounted for external and internal components linked to Company X. Secondly, by examining the technology available and the use of this technology in a real scenario, integrating multiple software to achieve the desired results, with adaptations as needed. And lastly, by identifying the benefits and disadvantages that can arise when utilizing VP. Figure 20 shows a summary of the stages described by company X in which the company introduces VP and the savings reported from it.

Figure 20. VP introduction by Company X



Source: Company X

Specifically, we could conclude that:

- Technology and innovation is driven by major global events, such as the economic meltdown in 2008 and 2009, which implicated in Company X's making their bigger changes in 2010 and 2020.
- Innovation is only possible in a company when people (staff) are interested in learning and challenging themselves to adapt and understand their opportunities and options.
- The company's size, where it is located, the market around it, the trade agreements in place, and the customers focus and location are big contributors to design companies' structure and orientation.
- There has to be an evaluation of market needs. Although there are many possibilities with VP, not all will be applicable to some companies. Currently,

some software offers a range of technological options, and not all will be required for your production method or from your customer.

- Workflows to adopt VP can be adapted according to the company's need. In Company X's examples, we noted that depending on the product they will need to combine VP and physical samples, depending on what they currently have, the product and the customer requirements.
- Physical samples are more expensive than VP, and at Company X there is up to 63% cost savings when producing VP.
- The cost difference between physical samples and VP at Company X ranged from $31.68 to $40.18 per unit. They reported to produce 7000 CAD designs per year, that is equivalent to $221,760 – $281,260 per year if 100% of the CAD designs were made digitally.
- From the cost analysis we can observe that labor is extremely important when comparing physical samples and VP cost. Although physical samples require more hours of labor, the cost/hour is less than half of the cost per hour of the VP designer. When looking at other countries, this can be very impactful, considering the rates and differences between skilled and unskilled labor. It is also important to note that labor cost is the only cost associated with VP.
- From the cost analysis we can also note that when making physical samples, the material impacts the cost significantly. Therefore, samples that require more dyes or expensive fibers are good candidates for VP, since they would represent more cost savings.

- We can conclude that VP can save time significantly. VP takes from 1-2 days to be made, while physical fabrics take at least 15 days. Savings in time represent saving in resources, and opportunity to take more business.

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APPENDICES

Appendix A
Interview Questions

DIGITAL PROTOTYPING IN THE TEXTILE INDUSTRY

We thank you for your time to participate in this interview which aims to explore the possibilities and constraints with virtual prototyping in the textile industry. If you agree to participate in this study, you will be asked to respond to a series of questions. There should be no risks associated with completion of this survey and there is NO monetary compensation, and your participation will be considered as completely voluntary. The interview is expected to take about 1 hour. All the information collected in this interview will be treated as confidential and none of your details nor information will be disclosed to other parties or made public. If you agree to participate in this study, please review the consent form provided. By signing your name in the printed copy, you indicate your consent to participate in this research.

Objective: to conduct a case study analysis on digital prototyping:

1. At what points of the product development process are you prototyping?

a. Yarn

b. Fabric

c. Product

d. Fit

e. Manufacturing

2. What software do you use for each step?

a. Yarn

b. Fabric

c. Product

d. Fit

e. Manufacturing

3. Did you encounter cost savings when digital prototyping? If so, what percentage do you anticipate that you save annually?

4. Did you encounter time savings when digital prototyping? If so, how much time do you save annually?

5. Do you believe that Digital Prototyping is more sustainable than physical prototyping? Please explain why or why not.

6. Did you find other advantages?

7. How do you use digital prototypes?

a. Internal aesthetic assessment

b. External aesthetic assessment

c. To assess fit

d. To determine cost and/or time

e. To determine manufacturability

f. Other

8. What type of technologies do you use to support digital prototyping?

a. CAD

b. Scanning/photography

c. Digital libraries

d. Color management systems

e. Other

9. Can you provide examples of your digital prototyping process?

10. What type of standards do you use or follow for digital prototyping?

11. Did you encounter any barriers when adopting digital prototyping?

12. Is there any process that you consider virtual prototyping to be inefficient? Please explain.

13. When was the decision to change to digital prototyping? Can you provide a timeline of the implementation of the technologies used?

14. What caused you to initiate the change to digital prototyping?

Appendix B

Interview Protocol

Participants will be selected according to expertise in the fields identified and through Principal Investigator (PI)'s contacts. After selecting the participants, the protocol will be as follows.

1. The participants will be asked to participate via email.
2. If participants agree to participate they will be asked to review and sign the IRB approved consent form.
3. Participants will be given a list of survey questions and asked for a time to meet to answer the questions. Survey participants will also be given an opportunity to send written responses.
4. The PI will write a summary of the survey responses and send it to each participant for review.
5. If possible, the researcher will visit the company interviewed for observation research and possible sample collection. For the in person meeting:
    1. All researchers will comply with the environment's requirements. This includes screening themselves for COVID-19 symptoms before interacting with any participants, may include wearing face coverings, etc.
    2. If no environmental requirements are in place, if the research team has symptoms, the research team will not interact with participants.
    3. Researchers may also opt to wear an n95 or kn95 face mask over their nose and mouth based on their own personal risk assessment.
    4. All researchers will wash their hands and use hand sanitizer before interactions with individual participants.
    5. All researchers will follow the established COVID-19 guidelines for the company visited throughout the research process.

Due to using a small expert participant group, and because some of the data collection will involve personal interviews and emails will be sent, participants will be identified by their name and company during the data collection process. However, all published material, including my thesis, will have no identification of participants. Participants will remain anonymous, unless they choose otherwise. The emails will be exchanged through the NC state accounts, secured by password and duo verification. Emails will only be shared with PI and advisor.

Appendix C

Recruitment Email

Hello, (Name)! I was referred to you from _____. I am a Master student at NC State in Textile Technology and Management, my advisor is Dr. Chapman. My research is in Virtual Prototyping, and I am conducting a case study to elucidate where this technology is being used and the possibilities with it. Your expertise would be a great contributor to my research. Your participation would consist in:

1) Reviewing the consent form.

2) A video call interview - the questions will be sent to you via email for your review before the interview.

3) After the interview, you will be allowed to review your interview responses, and to make revisions or corrections as needed.

Thank you in advance, and please let me know if you would be interested in helping me.

Best Regards,

Ana Musialak

+1 919 2083547

alalvesm@ncsu.edu

Appendix D

NC STATE UNIVERSITY

Informed Consent for Participation in Research

Exempt Survey Consent Form

Title of Study: Case Study: Virtual prototyping in the textile industry **(eIRB # 25466)**

Principal Investigator(s): Ana Luisa Alves Musialak, alalvesm@ncsu.edu, (919) 208-3547

Funding Source: None

You are being asked to complete an interview for research purposes. The interview is about Virtual prototyping in the textile industry. Completing this interview is voluntary and you can stop at any time by simply not responding and sending an email to the Principal Investigator.

As a part of this research, I would like your consent to visit your company site, and collect data such as physical textile samples and images of products or machines.

You must be 18 years of age or older, and speak English to participate in this study.

There are minimal risks associated with your participation in this interview. You will not receive any payment for completing this interview.

If you have any questions about the interview, how it is implemented, or the research study, please contact the researcher, Ana Luisa Alves Musialak at alalvesm@ncsu.edu and (919) 208-3547. You can also contact the faculty advisor for this research, Lisa Chapman, at llparril@ncsu.edu. Please reference study number (**eIRB # 25466)** when contacting anyone about this project.

If you have questions about your rights as a participant or are concerned with your treatment throughout the research process, please contact the NC State University IRB Director at IRB-Director@ncsu.edu, 919-515-8754, or fill out a confidential form online at https://research.ncsu.edu/administration/participant-concern-and-complaint-form/

If you consent to complete this interview, please reply to this email informing your willing to participate in this research.