HARTIS, PEYTON LEANNE. 3D Apparel Visualization Technology Customization for Pants Based on Three Body Types. (Under the direction of Dr. Cynthia Istook).

The purpose of the study was to further research the development of pants for specific body types with the use of 3D apparel visualization. In literature, there is research on the 3D software and the development of garments, as well as research on body shapes for women. There was limited research on developing garments specifically for the different female body shapes while using 3D technology.

The research was conducted in two parts. The first portion involved recruiting and body scanning females between the age of 18 to 30 years old. A total of four participants volunteered, and three different body shapes were identified; rectangle, oval, and triangle. Using the measurements from the body scan, three pant patterns were developed to represent each body shape that was identified, while using the same amount of ease. For each of the three shapes, there was a software generated avatar and an OBJ avatar that was imported from the point cloud data of the body scan. In the second portion of the research, a survey was sent out to members in the textile and apparel industry to provide insight on their opinion of 3D apparel visualization, as well as rate the fit of the pants developed in the first portion of the research. A total of 35 participants took the survey, and all had varying backgrounds and years of experience within the textile and apparel industry.

Analyzing the results provided many interesting insights. All survey participants were interested and felt that 3D software should be used in the industry even if the end-use varied. The participant pool was not large enough to determine if job function or years of experience were influential in the fit rating of the pants. It was discovered that a significant number of respondents showed interest in using body scan avatars. However, the fit ratings of the
software native avatars showed significant preference over the body scan avatars. The information obtained from this research will help further define the capabilities of 3D apparel visualization technology and the need to have more inclusive sizing options for women.
3D Apparel Visualization Technology Customization for Pants Based on Three Body Types

by
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A thesis submitted to the Graduate Faculty of
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DEDICATION

To my supportive parents,
Samthya and Gene Hartis:
I could not be where I am today without your love, support, and constant encouragement to make my education one of your top priorities.
BIOGRAPHY

Peyton Leanne Hartis was born on April 14, 1996, in Wilmington, North Carolina. In 2014, she graduated as Valedictorian from North Brunswick High School in Leland, North Carolina. She attended North Carolina State University where she graduated Summa Cum Laude with a Bachelor of Science degree in Fashion and Textile Management with a minor in Design Studies in May 2018.

Peyton’s passion for textiles and learning motivated her to participate in the Accelerated Bachelor’s Master’s Program where she continued to graduate school after graduation. She is a candidate for a Master of Science in Textiles at the Wilson College of Textiles.
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# TABLE OF CONTENTS

LIST OF TABLES ......................................................................................................................... viii

LIST OF FIGURES ......................................................................................................................... ix

CHAPTER ONE: INTRODUCTION ................................................................................................. 1
  Purpose ......................................................................................................................................... 3
  Research questions ..................................................................................................................... 3
  Definitions: ................................................................................................................................... 4
  Limitations .................................................................................................................................... 5
  Assumptions ................................................................................................................................. 6

CHAPTER TWO: LITERATURE REVIEW ....................................................................................... 7
  Mass Customization .................................................................................................................... 7
  Industry patterns ........................................................................................................................ 8
  Prototyping process .................................................................................................................... 9
  Apparel Technology ................................................................................................................... 10
    Computer-aided-design (CAD) ................................................................................................ 10
    Two-dimensional (2D) pattern making software ................................................................. 10
    Three-dimensional (3D) pattern making software .............................................................. 11
    Two-dimensional vs. three-dimensional pattern making ..................................................... 16
  Body scan technology .............................................................................................................. 17
  Avatars vs. Human Body Scans ............................................................................................... 18
  Size Stream ............................................................................................................................... 19
  Fit and Sizing ............................................................................................................................ 20
    Women sizing methods ......................................................................................................... 20
    ASTM ....................................................................................................................................... 21
    Grading ..................................................................................................................................... 22
    Pant patterns and fittings ....................................................................................................... 22
  Female Body Types .................................................................................................................. 24
    Female Figure Identification Technique (FFIT) ................................................................. 25
    Female figure body shapes .................................................................................................... 25
      Hourglass ............................................................................................................................ 25
      Top hourglass .................................................................................................................... 26
      Bottom hourglass .............................................................................................................. 26
      Spoon .................................................................................................................................... 26
      Rectangle ............................................................................................................................. 27
      Diamond ............................................................................................................................. 28
      Oval ...................................................................................................................................... 28
      Triangle ............................................................................................................................... 29
      Inverted Triangle ............................................................................................................... 30

CHAPTER THREE: METHODOLOGY ............................................................................................. 31
  Research Questions .................................................................................................................. 31
  Research Design ....................................................................................................................... 31
  Part One ..................................................................................................................................... 32
    Garment design ..................................................................................................................... 32
Body shape identification ................................................................. 32
Body scanning .................................................................................. 32
FFIT for Apparel ............................................................................. 33
Garment alteration .......................................................................... 33
Garment draping ............................................................................ 34
Avatar prep ....................................................................................... 34
Fabric preparation .......................................................................... 35
CLO 3D Fabric Kit ........................................................................... 36
Fabric emulator ............................................................................... 37
Image collection .............................................................................. 37
Part Two .......................................................................................... 38
Selection of Subjects ....................................................................... 39
Development of Survey .................................................................. 39
Survey Distribution ......................................................................... 39

CHAPTER FOUR: PRESENTATION OF DATA ........................................... 41
Description of Sample ..................................................................... 41
Data Analysis .................................................................................. 43
Research Q1: ................................................................................... 43
  Q1A ............................................................................................... 46
  Q1B ............................................................................................... 48
Research Q2: ................................................................................... 50
Research Q3: ................................................................................... 52
Research Summary ......................................................................... 54

CHAPTER FIVE: DISCUSSION, IMPlications, & RECOMMENDATIONS ........ 55
Discussion of Results ....................................................................... 56
  Discussion of Pant Development for Body Shapes ......................... 56
  Using Software Avatars and Imported Body Scans ....................... 57
Research Questions .......................................................................... 60
Recommendations for Future Research ........................................... 61
Conclusions ...................................................................................... 62

REFERENCES .................................................................................. 64
APPENDICES .................................................................................... 74
Appendix A: Pattern Images ............................................................... 75
Appendix B: Final Garments ............................................................... 77
Appendix C: Participant Recruitment and Communication ................ 85
Appendix D: Body Scans .................................................................... 90
Appendix E: Measurement Charts .................................................... 92
Appendix F: Cross Section ............................................................... 95
Appendix G: Survey .......................................................................... 96
LIST OF TABLES

Table 1. Ease Chart (in inches) for Pants ................................................................. 34
Table 2. Comparison Chart between Each Model (in inches) ......................... 35
Table 3. Fabric Test Data from the CLO 3D Test Kit ........................................ 37
Table 4. Summary of Methodology ........................................................................ 40
Table 5. Participant Opinion from Those Who Use 3D Apparel Visualization .... 45
Table 6. Participant Input on 3D Apparel Visualization Utilization ....................... 45
Table 7. Pant Fit Rating for Each Body Shape ......................................................... 51
Table 8. Mean Pant Fit Rating Comparison for Each Body Shape ..................... 52
Table 9. Pant Fit Rating Comparison for Each Body Shape Avatar Against the Control. .... 52
Table 10. Participant Preference Selection Between the Avatar and OBJ for Each Body Shape 54
LIST OF FIGURES

Figure 1. Example of CLO avatar and pattern (3D and 2D window) ...................................................... 12
Figure 2. Example of CLO avatar arrangement points ............................................................................. 13
Figure 3. Example of CLO 3D virtual stitching ....................................................................................... 15
Figure 4. Example of Size Stream body scan and measurements .............................................................. 19
Figure 5. 2D pant pattern in Gerber Accumark Pattern Design software ............................................. 23
Figure 6. Example of an Hourglass (Simmons, 2002, 104) ................................................................. 25
Figure 7. Example of a Bottom Hourglass (Simmons, 2002, 107) ....................................................... 26
Figure 8. Example of a Spoon (Simmons, 2002, 113) .............................................................................. 27
Figure 9. Example of a Rectangle (Simmons, 2002, 116) ................................................................. 27
Figure 10. Example of a Diamond (Simmons, 2002, 119) ...................................................................... 28
Figure 11. Example of an Oval (Simmons, 2002, 121) .......................................................................... 29
Figure 12. Example of a Triangle (Simmons, 2002, 124) ...................................................................... 29
Figure 13. CLO 3D fabric emulator test kit and fabric .......................................................................... 36
Figure 14. Photo apparatus used to take a high definition photo of the fabric ........................................... 38
Figure 15. Participants’ current job title .................................................................................................. 42
Figure 16. Participants’ years of experience in the industry ................................................................. 42
Figure 17. Participants’ product category experience .......................................................................... 43
Figure 18. Participant interest in how 3D tools should be utilized ............................................................ 44
Figure 19. Overall pant fit rating per job function .................................................................................. 47
Figure 20. Avatar pant fit ratings by job function .................................................................................. 47
Figure 21. Body scan (OBJ) pant fit ratings by job function ................................................................. 48
Figure 22. Participants’ years of experience ......................................................................................... 49
Figure 23. Overall pant fit rating per year of experience ....................................................................... 49
Figure 24. Avatar pant fit ratings by years of experience ....................................................................... 50
Figure 25. Body scan (OBJ) pant fit ratings by years of experience ..................................................... 50
Figure 26. Avatars with the same pants: software generated (Left) & body scan/OBJ (Right). . 60
CHAPTER ONE: INTRODUCTION

Within the fashion and textile industry, there have been many innovations with tools, machinery, development, and production. One of the main issues that continue to circulate is how to improve the fit of garments for consumers, while also reducing the amount of time that is spent in the process. The process begins a year in advance and the actual development of the product can take several months and influence the total time to market. Designing and developing products often takes the longest. Multiple physical prototypes are usually developed contributing to textile waste (Gill, 2015). The product development process is comprised of multiple steps. Products are designed, tested, refined, manufactured, and shipped. Each step of this process is crucial because it will impact the outcome of the final garment. There are multiple garment prototypes created until the final product meets the fit and aesthetic requirements of the designers and product developers (Jhanji, 2015). By creating many prototypes with no end use, this can often become unsustainable and takes more time for the overall product development process.

The fit of garments is an important factor for consumers, therefore it is has become a higher priority for those in industry developing garments (Gill, 2015). Since not every human body is made the same, it is difficult to mass produce garments that will fit properly for everyone. Although there have been improvements through technology, grading, and other researched techniques, there is no garment that fits all. Women’s pants are one of the more difficult garments to fit because of various leg lengths, crotch depths, and hip girths, which do not always correlate in measurements. Due to these fit inconsistencies, consumers are often dissatisfied and may have to have the pants altered to fit.
Female bodies have been classified into nine different body shapes (Simmons, Istook, & Devarjan, 2004) that have generalized, but unique, features. Some women have wider hips or a longer leg length, and there have been studies in which measurements correlate more within each body shape classification (Simmons, Istook, & Devarjan, 2004). Creating an appropriate fit is often difficult because there is no set industry standard that all brands follow. ASTM, formerly the American Society for Testing Materials, has developed body measurement descriptions to be used as guidelines for industry to use when developing products (ASTM, 2019). These various standards (ASTM D5219, D5585, D5586, D6829, etc.) change often, but fail to represent even the most common shapes of the target population. If basic pant pattern blocks were developed to support the varied body shapes that have been identified, there could be improvements in the fit of pants for a wider variety of body shapes.

Time constraints and fit issues are causing more companies to transition to using 3D apparel visualization technology. Although using 2D pattern making technology is an alternative method to flat pattern making by hand, it does not allow the designer to see specific fit issues with their pattern design. By bringing 2D patterns into a 3D environment, the designers can visualize what the final garment will look like while being able to determine obvious fit issues without constructing a physical garment. This process can at least eliminate much of the physical prototyping that has been generally required. Another benefit of the software is that it can improve communication between designers and manufacturers when discussing specific issues with fit and allows issues to be visualized more easily. Although there are some inconsistencies with using 3D apparel visualization technology, it has many benefits that may allow the industry to further advance while benefitting consumers.
Purpose

The purpose of this research study was to assess the virtual evaluation of pants fit considering three different body types and two types of avatars. The three primary body types selected are the most prevalent for women 18-30 years old.

Significance of the Study

If garments can be developed based on body type sizing versus general apparel sizing, better fitting garments could be available to fit more consumers. The use of 3D technology may enable a quicker and more sustainable evaluation of the garments developed for more unique bodies. This will allow for faster fit evaluations, less prototype waste, and a reduction in the amount of time spent in the product development phase.

Research questions. The goal of this research was to answer the following questions regarding 3D apparel visualization and fit based on body types.

1. Can 3D software programs be used to visualize the fit and design of pants?
   a. Is the ability to visualize the fit and design of garments influenced by job function?
   b. Are years of experience an influencing factor when evaluating fit from the 3D software simulation?

2. Of the three shapes studied (rectangle, oval, triangle), how does the body shape of the model impact virtual fit evaluation in 3D software programs?

3. Can a software generated avatar and an imported body scan avatar be evaluated equally when wearing the same pair of pants?
Definitions:

- **Textile and Apparel Computer Aided Design (CAD):** Computer systems used to assist designers in the development of products, which include but are not limited to 2D pattern making, 3D pattern making, and body scanning.

- **3D Apparel Visualization Technology:** A form of CAD technology that uses 2D patterns that can be virtually sewn together to provide a visual image of the garment on a virtual model, while also allowing designers to view fabric choices, colors, textures, and drape (Jhanji, 2015).

- **American Society for Testing and Materials (ASTM):** An international standards development organization (ASTM International, 2019). For this research, the *ASTM D5585-11 Standard Tables of Body Measurements for Adult Female Misses Figure Type, Size Range 00-20* was be used.

- **Fit:** An objective term used to describe how garments appear on the body in terms of tightness, looseness, and length. In this study, pants were evaluated based on the waist, hips, crotch depth, and inseam.

- **Female Figure Identification Technique (FFIT):** A system developed to identify the primary body shapes of women based on body measurement ratios (Simmons, Istook, & Devarjan, 2004).

- **Mass Customization:** A process developed to allow companies to produce individually customized products or services based on a mass production framework (Pine, Davis, & Pine II, 1999).

- **Anthropometric:** Measurements of the human body.
● Prototypes: garments developed during the product design phase to determine the fit and visual appearance when being worn on a body.

● Body shapes: a compilation of specific body measurements, specifically bust, waist, and hips, with specific ratio values that are used to categorize the general difference between women. These categories have been called hourglass, spoon, oval, diamond, triangle, etc.

● Crotch Depth (Rise Height): the vertical distance from the waist level at the side of the torso to the crotch level taken with the subject standing (ASTM, 2015)


● Hip/Seat Girth: “measure the maximum horizontal circumference around the body at hip height” (ASTM, 2, 2015)

● Thigh Girth: “measure the maximum horizontal circular circumference of the upper leg taken closer to the crotch” (ASTM, 2, 2015)

● Mid-Thigh Girth: “the maximum horizontal circumference of the upper leg, taken midway between the hip girth level and the midpoint (or crease) of the knee” (ASTM, 2, 2015)

● Grading: the transition of a base pattern to other sizes without influencing the shape, fit, and balance of the original pattern.

Limitations. The following were the potential limitations of this study.

● Only three body shapes were evaluated and the differences between those shapes were not large. A convenience sampling method was used with college aged students, who might not be representative of the breadth of sizing within the shapes of interest.

● Only women’s pants were tested.

● Only one type of 3D pattern making technology (CLO 3D) was used.
• Only one physical garment was sewn (the control) to use as a comparison product.

• The ability to adjust the system avatar’s measurements was controlled by the software.

• Many of the measurements were linked so that when one measure was changed, others would also be changed. This did not always reflect the real shape of the human subjects used in this study.
  
  o The body files (.obj) obtained through body scanning were not adjustable.

  Without extensive preparation, these images could not be manipulated (for movement).

Assumptions. The following were assumptions made during this study.

• The fabric displayed in the 3D virtual technology accurately represented the physical fabric.

• The 3D technology accurately displayed fit issues with the pants that might help to reduce prototypes and time to market.

• One garment does not fit all body shapes.
CHAPTER TWO: LITERATURE REVIEW

Developments in 3D virtual prototyping systems appear to have the potential for use in the apparel industry to reduce product development time, improve the fit of garments and reduce waste. The purpose of this research study was to compare the fit appearance of virtual garments developed for 3 specific female body types using 3D apparel visualization technology. To provide a foundation for the research study, the following topics were addressed: 1) mass customization, 2) apparel technology, 3) fit and sizing, and 4) women’s body types.

Mass Customization

More companies within the textile and apparel industry are transitioning towards using mass customization within their product lines. Mass customization allows companies to produce mass amounts of products while allowing individual customization to their products and services (Pine, Davis, & Pine II, 1999). As Joseph Pine II (2004) explained, “There are few industries more ripe for being revolutionized by mass customization than the apparel industry, for the simple reason that everybody is unique!” (Pine II, 2004, 3). Many other industries have been using mass customization processes for many years, such as automobiles and computer technology (Pine II, 2004). However, this has taken some time to transition into the textile and apparel industry.

Many consumers want to add personalization to their apparel choices (Su et al., 2015; Yang et al., 2007). Within the apparel industry, mass customization allows the consumer to have more input on the garment that is purchased by making decisions on color, silhouette, and some minor design features. This concept has helped retailers since billions of dollars are wasted each year due to unsold inventory (Pine II, 2004). These customized products are expected to have a higher quality and faster delivery due to the benefits provided by this new technology (Su, Liu,
& Xu, 2015). To achieve this concept of mass customization, apparel manufacturers must undergo some changes, as well as incorporate technology like 3D body scanning, automatic pattern making systems, computer-aided manufacturing, apparel fitting software, and advanced operations (Su, Liu, & Xu, 2015).

Consumers desire products and services that are affordable and unique to their desires (Apeagyei & Otieno, 2005; Bart and Boynton, 1998; Kotler, 1997; Seo & Lang, 2019; Simmons and Istook, 2003). Some companies such as Brooks Brothers have taken this concept into account when developing products. Brooks Brothers allow men to customize their dress shirts and suits in their online Customized Shirts & Suits (Brooks Brothers, 2019). It allows men to customize the fit of the silhouette, collar size, and sleeve length. Details like the fabric, pocket, back pleats, collar, cuffs, and monogram can be adjusted to the consumer’s preference (Brooks Brothers, 2019). Although mass customization allows for consumer input, it is not the same as customization. Mass customization is a mix between mass production and customization to maximize consumer satisfaction while minimizing inventory costs (Power, 2012; Yang, Zhang, & Shan, 2007). With customization or couture, garments are made specifically for the individual. In mass customization, some consumer input is allowed but with certain preset features and limitations to pick from. Mass customization is gaining popularity as it becomes an important concept of manufacturing.

**Industry patterns.** Within the apparel industry, brands have their own variations of sizing methods and patterns. The most common sizing standard has been established by ASTM with Missy sizing ranging from 00 to 20. Many men and women are not satisfied with the fit of their garments (Ashdown & Dunne, 2006; Brownbridge, et. al., 2018; Desmarau, 2000; Gill, 2015; Labat & Delong 1990). These patterns vary based on the brand’s target consumer and
there are no set regulations in place. The brands that have broader market focus tend to have more fit dissatisfaction due to the dissimilar shapes and sizes of their consumer targets (Ashdown & Dunne, 2006).

Another important tool for mass customization is the development of a Made to Measure (MTM) system. With the transition to mass customization, there are more demands for fast, personalized garments (Liu, et. al., 2018). MTM systems help maintain design elements while creating apparel to fit consumers and their needs (Istook, 2002; Su et. al., 2015). In some MTM systems, a pattern grading method is utilized that correlates with sizing and alteration tables to be adjusted to a specific body (Istook, 2002; Su et. al., 2015). Alteration tables are necessary to help with significant fit problems that may occur at the chest, back, high-hip, and thigh girth (Power, 2012; Yang, Zhang, & Shan, 2007). Other Computer Aided Design (CAD) tools are help develop patterns for mass customization.

Prototyping process. During the product development phase of designing garments for the market, prototypes are made to determine the overall fit and appearance of the garments. Multiple prototypes are made to refine the fit and design of the product. This process can take a considerable amount of time because the garment is made and shipped between designers and manufacturers (Gill, 2015). Although it takes some time, it is important to get the fit and design details correct because this can impact consumer purchase decisions. The industry is transitioning to apparel visualization tools because of extended time implications. Visualization tools allow designers to work with a 3D avatar to adjust fabrics and patterns before making any final design decisions (Apeagyei & Otieno, 2005). The use of these tools may benefit designers, manufacturers, and consumers (Apeagyei & Otieno, 2005).
Apparel Technology

**Computer-aided-design (CAD).** Computer aided design has been a helpful resource to apparel and textile designers because it allows them to create designs and patterns more quickly. There have been many technological advances within the textile and apparel industry to help improve materials utilization, productivity, and precision (Istook and Hwang, 2001; Jhanji, 2015; Nayak et al., 2015; Yan and Fiorito, 2002; Wang et al., 2005). Technology and computer programs help reduce slow paced, time consuming, and labor intensive operations (Jhanji, 2015; McCartney et al., 2000; Nayak and Padhye, 2015a,b;).

There are a wide variety of software programs used within the industry that assist designers with daily tasks. These include fashion research, fashion design and illustration, pattern design, pattern making, textile design, garment construction, production management, marketing, and sales (Istook and Hwang, 2001; Jhanji, 2015; Nayak et al., 2015; Yan and Fiorito, 2002; Wang et al., 2005). CAD systems also help in implementing the mass customization process (Apeagyei & Otieno, 2005). CAD technology allows for more flexibility with pattern making, reducing fabric waste, improving the quality of marker cutting, and reducing time in pre-production phases (Jhanji, 2015; Luo and Yuen, 2005; Zoran, 1995). These programs have helped to shorten the time to market and improve the overall time efficiency in the product development phase.

**Two-dimensional (2D) pattern making software.** There are several different patternmaking software programs used by industry, but two of the more known are *Gerber Accumark* and *Lectra Modaris* (Jhanji, 2015; Power, 2012). Two-dimensional (2D) pattern making software allows designers to develop patterns directly within the program or convert paper patterns that have been scanned or digitized into the system. These software programs
allow for direct manipulation of pattern pieces and allow files to be easily stored and retrieved to be reused for future designs (Jhanji, 2015). Patterns can be edited more quickly, graded to various sizes, laid more efficiently in markers to reduce fabric waste, and sent to a computer controlled automatic cutting system for speedy and precise cutting (Jhanji, 2015; Luo and Yuen, 2005; Zoran, 1995). Although 2D pattern making can be useful and help designers work more efficiently, it is not always possible to determine any fit issues with the garment until after it is cut and sewn. Fit issues cannot be found within the flat pattern, so prototypes are necessary to make sure there are no fit issues and appear the way designers intended.

Three-dimensional (3D) pattern making software. In recent years, 3D pattern making software has become more popular within the apparel industry. This software allows designers to view their 2D patterns sewn together to provide a visual image of the garment on a virtual model (Gill, 2015; Jhanji, 2015; Kim et al., 2017; Stylios et al., 1996). There are different ways patterns can be utilized in 3D software. Some patterns are created in 2D software programs and converted to a dxf format to be imported into 3D software programs (Liu et al, 2018; Song & Ashdown, 2015). Other methods include developing the patterns in the 3D software program or drawing directly on the avatar to create a pattern and flattening those patterns from 3D to 2D (Liu et al, 2018). A sample of the 3D software program can be seen in Figure 1, which shows the 3D and 2D windows.
When working in a 3D apparel visualization environment, many components must be considered. Mechanical properties of clothing are considered since different fabrics and materials interact with bodies differently regarding fit and movement, which could impact the design visualization (Apeagyei & Otieno, 2005; Aldrich, 2004; Volin and Magnenat-Thalmann, 2000). The virtual software also allows designers to view fabric choices, colors, textures, and some drape to gain an idea of the final garment (Fontana et al., 2005 a,b; Jhanji, 2015; Kim & Labat, 2013). Some of the 3D software programs allow the automatic placing of pattern pieces so that changes can be made and visual effects can be added (Jhanji, 2015). The automatic placing of pattern pieces using arrangement points can be seen in Figure 2.
The use of 3D visualization software helps reduce time and fabric waste because the garment can be visualized, and major fit issues can be seen before the first garment is ever made. In previous studies, it was shown that the use of 3D virtual fitting technology allows for fewer physical prototypes to be developed, time is reduced to design and develop prototypes, and production costs are lowered (Song & Ashdown, 2015; Power, 2012; Salmon, 2014). Companies are also using 3D pattern making software to visualize the garment’s fit and appearance before production (Kim & Labat, 2013).

For garment simulations to appear realistic, it is important to capture the mechanical behavior of the fabric to determine how it interacts with the body and other materials. Proper input of fabric parameters is essential (Luible & Magnenat-Thalmann, 2007; Power, 2012). Fabric is an area of difficulty because developers are still working to accurately represent fabric in the software by showing its stretch, draping properties, and texture (Jhanji, 2015; Kim &
In virtual garment simulation, objective measurements of fabric are used to represent fabric properties (Power, 2012). These objective measurements are obtained from fabric testing that is often established by the 3D virtual apparel software programs. The fabric kits test different tensile and bend properties that are input into software programs (Power, 2012).

The 3D software cannot be used as the only visual analysis tool because of its inability to show smaller fit issues (Gill, 2015; Song & Ashdown, 2015; Kim & Labat, 2012). For example, small folds or slight tightness or looseness, and stress folds are not always visible within the 3D software. In other studies, the virtual garment did not show the stress folds when compared to the physical prototype that did contain stress folds and minor fit issues (Song & Ashdown, 2015; Kim & Labat, 2013). Even in the current software state, 3D technology can help shorten the response time for buyers and manufacturers, and there is less need for physical samples to be made (Jhanji, 2015). It can also help technical designers, pattern makers, and designers to communicate any fit issues instead of relying just on pictures and the tech pack (Salmon, 2014; Song & Ashdown, 2015; Speer, 2008; Yoon, 2013).

Most programs operate by using a parametric virtual mannequin that has been imported from a 3D body scan or adjusted within the system (Kim & Labat, 2013; Song & Ashdown, 2015). Seams of patterns must be paired for virtual stitching, the patterns placed around the virtual mannequin, and the mechanical properties of fabrics applied before simulating virtual stitching and draping (Song & Ashdown, 2015). Figure 3 displays an example of virtual stitching in a 3D program.
There are several 3D software systems available, but two of these programs include CLO 3D and Optitex. CLO 3D is known for creating intricate details, layering, avatar arrangement points to place pattern pieces on the avatar (as shown in Figure 3), and real-time interactivity with a strong fabric database that has drape sensitive fabric information (CLO, 2019). Optitex 2D/3D CAD system allows 2D pattern design and grading that can be translated to their 3D virtual sample generator, and a virtual tension map is available (Optitex, 2019). Both programs offer virtual stitching (as shown in Figure 4) and avatar editing. Some retailers like Target and Kohl’s are incorporating Optitex’s 3-D Runway Creator for PDS into their product and prototype development process to communicate their designs with vendors (Salmon, 2014; Song & Ashdown, 2015; Yoon, 2013).

According to research by Song and Ashdown (2015), virtual fit technology is accurate for pants with a good fit, but cannot be a complete replacement for physical prototypes, only as a
visual analysis tool (Song & Ashdown, 2015). The issues that these researchers encountered when working with 3D apparel visualization software include: the waist placement on the virtual pants was not in the same location as the real pants, the 3D garment showed no stress folds compared to the real garment, the silhouette was distributed differently, the body shape was an influencing factor, and the virtual fabric properties did not resemble those of the real fabric (Song & Ashdown, 2015). In another study by Kim and Labat (2013), the researchers had similar findings in that 3D apparel visualization software provided a good visual to evaluate fit but did not always show accurate fit details from the virtual garments (Kim & Labat, 2013).

**Two-dimensional vs. three-dimensional pattern making.** There are positives and negatives when using 2D and 3D pattern making software programs. Software that uses anthropometric data is important in allowing the textile and apparel industry to progress and have become vital resources within the industry (Apeagyei & Otieno, 2005; Song & Ashdown, 2015; Wolny, 2002). The industry continues to use 2D software programs and physical prototypes because the process is reliable. Companies are working towards a transition from 2D to 3D design programs due to the high demand of being able to visualize the garment before physical samples are made (Jhanji, 2015).

Garment ease is an important consideration when designing in both 2D and 3D pattern making software programs (Liu et al., 2018). Basic ease allowances focus on the distance between the garment surface and body surface of the wearer at key points like the bust, waist, and hip, which allow the wearer to move more freely and comfortably (Liu et al., 2018). Although 3D can help reduce some of the prototypes, a physical prototype is often still necessary (Gill, 2015; Song & Ashdown, 2015).
Body scan technology. Three-dimensional body scanning is another technology that is becoming popular in the apparel industry. Body scanning is used in a variety of areas within the industry, especially for academia and research, as well as commercial applications (Ashdown & Dunne, 2006; Haisley, 2002; Mastnak, 2000). Companies are using the technology in many ways including obtaining measurements, creating 3D avatars, and creating interactive shopping environments for consumers. Body scanners scan the human body to gain anthropometric data and form a point cloud of data in which measurements can be extracted to replicate the model (Jhanji, 2015; Power, 2012). Three-dimensional body scanners can generate over 100 measurements within a few minutes, whereas manual measuring is laborious and less accurate (Song & Ashdown, 2013; Textile/Clothing Technology Corporation, 2011). Body scanning technology can not only collect more measurements faster, but it also captures the image of the individual being scanned which can help companies determine body shapes and sizes to improve their current sizing systems (Song & Ashdown, 2013). Most of these scans are accurate, but some inaccuracies can occur (Gill, 2015).

There are different types of 3D body scanning and methods that are used. Body scanners collect measurements using light sources, cameras, or other capturing devices that are connected to a computer software system and monitor to visualize the captured data (Vuruskan & Bulgan, 2010). Some body scanners use laser and light projection, where cameras detect the reflected light deformed due to the object shape, and the displacement of light is what allows the scanner to form the 3D points (Daanen & Water, 1998; Fan et al., 2004; Vuruskan & Bulgan, 2010).

There are handheld scanners, mobile scanners on phones, and laser scanners. There are large body scanning systems like TC2, Tukatech Styku, and Size Stream. The Styku scanner uses a V2 depth Sensor and turntable to capture the body, while the software segments the body into
regions and significant features (Gill, 2015; Styku, 2019). TC² scanners use infrared depth sensors to extract measurements to be sent to a defined software program (Gill, 2015; [TC]², 2019). Some body scanning software systems use laser light image capturing devices to record measurement points on the body and form the point cloud (Gill, 2015).

When using body scanning systems, it is important to look for issues or inaccuracies that can potentially occur. Scanning posture is important because occlusions can occur around the waistline, crotch point, and arm points (Gill, 2015; Kim & Labat, 2012). The scanner cannot recognize the point at which the body and the limbs connect since those locations have obstructed views. Light can also influence the outline of the body and how it is captured by the scanner (Gill, 2015). These body scans can be converted into avatars and imported into 3D pattern making software programs.

**Avatars vs. Human Body Scans.** An avatar is a tool in 3D software programs that reflect human body measurements to show fit visualization. These avatars are created to look like humans to appear more realistic (Gill, 2015). Avatars can be created by importing a 3D body scan or obj file, or by adjusting the parametric model’s body measurements (Song & Ashdown, 2015). Avatars or parametric models within 3D software programs are proportional bodies that are not always representative of the human population. The measurements are linked so if one part of the body is adjusted, some of the other parts will adjust in correlation. With the use of 3D body scanning, virtual avatars can be developed by using human body measurements (Kurokawa, 1997; Power, 2012; Stylios et al., 2001; Wang and Zhang, 2007; Xu et al., 2002; Xu and Svinivasan, 1999). With body scanning, the files go through a conversion process to be converted to an avatar. These point clouds are converted to triangular meshes as surface layers that are repositioned and merged into different layers to form a complete human body surface
(Tao & Bruniaux, 2012). The parametric model often varies from the actual human body shape and may contain more dimensions than the model created from the 3D body scan (Lim & Istook, 2011; Song & Ashdown, 2015). The avatars created from body scans are more representative of actual human bodies and are more accurate because the measurements are not adjusted (Kim & Labat, 2012).

**Size Stream.** Size Stream is one of the body scanning devices available which uses a scanning booth. The scanner uses 14 PrimeSense infrared depth sensors and captures anthropometric data in less than 8 seconds; 420 data points are collected to form a point cloud (Gill, 2015; Size Stream, 2019). The scanner creates an .obj file that can easily be converted to an avatar and imported into a 3D software program. The measurements and body scan that the SizeStream scanner produces can be viewed in Figure 4.

![Image of Size Stream body scan and measurements](image)

**Figure 4.** Example of Size Stream body scan and measurements.
Fit and Sizing

Women sizing methods. The U.S. Department of Commerce established a sizing standard in the 1950s, but the apparel industry was not required to follow these standards (Faust et al., 2006; Kim et al., 2016). ASTM began developing a standard in the 90s for a variety of generic markets (Missy, Junior, Plus Size, Mature, etc.). Most companies create their own sizing system by developing size charts to fit their target market and adjusting based on consumer input and merchandising reports (Kim et al., 2016; Petrova, 2007). The fit of clothing is an important element in determining the quality and consumer satisfaction, but it is difficult to determine because the fit is both objective and subjective depending on the individual consumer’s perception (Song & Ashdown, 2010). Brands use their fit and sizing systems as part of their marketing strategy since it is unique to their apparel products.

When making patterns and grade rules, especially for ready to wear apparel, it is important to keep the target market in mind and adjust the base pattern (Zhang, Kim, & Takatera, 2016). It is also important to consider all body proportions when grading the base pattern because girth and vertical measurements vary (Zhang, Kim, & Takatera, 2016). Body sizing systems are developed based on each company or brand’s target market. Anthropometric data is taken the target market to create patterns and grade rules so that the products developed will be more specific to that group (Petrova & Ashdown, 2012).

The size of the garment is dependent upon body sizing, but it is difficult to determine what will categorize these sizes and how much ease to add for each size. Ease allowance is determined during the fitting of the garment and influences pattern grading and size development because different body sizes require different amounts of ease. (Bye et al., 2008; Petrova & Ashdown, 2012; Wang and Huang, 2011; Zhang, Innami, Kim, Takatera, 2015). Apparel
companies design clothing for an average height and weight for their customer (Faust & Carrier, 2010; Kim et al., 2016), but according to SizeUSA data the industry average is not representative of the population (Kim et al., 2016; Textile Clothing Technology Incorporated, 2004). Not every consumer will be satisfied since each person is unique, but those who fall within the average of the brand’s target market will have a better chance of finding clothes to fit. These processes are dependent upon one another, but each step of the sizing and pattern making process is necessary to provide quality fitting garments.

**ASTM.** ASTM (formerly the American Society for Testing and Materials) is an international standards development organization comprised of industry members (ASTM International, 2019). ASTM has worked to develop standard sizing systems for different genders and age populations. For this research, the *ASTM D5585-11 Standard Tables of Body Measurements for Adult Female Misses Figure Type* standard was used. This specific standard sizing system has different variations of sizing from missy straight, slim, and curvy. This data was collected based on human sizing samples from the U.S. Department of Commerce, the Caesar Study, and the Size USA study, as well as independent industry data. The measurements are grouped within a size from 0-20 (ASTM, 2011). The ASTM sizing standard took precedent in 1995 when it issued the ASTM D5585 Standard Table of Body Measurements for Adult Female Misses Figure Type and was updated in 2011 after the SizeUSA data was published (Kim, Song, & Ashdown, 2016). Petrova and Ashdown (2012) discovered that most women do not fit within the ASTM sizing system. With the new version in 2011, ASTM updated the grading from size to size. Before the update, grading was based on one inch, one and a half-inch and two-inch growths, with the largest sizes having the largest grades. The update reflects various grades from one size to the next (rather than consistent grades) to include more body
shapes by having straight and curvy systems and smaller bust-hip drops. Researchers realized sizing systems based on modified body sizing tables and size-dependent ease grading provide a better fit (Petrova & Ashdown, 2012). However, this inconsistent grading method means that the shapes within the system are also changing. This was one method to try to respond to how bodies change as weight is added or subtracted.

**Grading.** The process of grading allows for patterns to transition to different sizes while maintaining their integrity. Each corner of the pattern is expanded or retracted a certain amount from the base pattern to determine the next size. Before CAD and other computerized systems, grading was performed manually with complicated calculations and time-consuming work to scale the pattern for different sizes (Hanford, 2003; Jhanji, 2015). Now with CAD grading systems, pieces can be graded, while also adjusting notches, alteration rules, and darts in a quick and easy step without influencing the shape, fit, and balance of the original pattern (Jhanji, 2015).

Issues with fit can be traced to pattern grading and the sizing system used (Ashdown and Dunne, 2006). For grading to occur, grade rules have been established so that the pattern will adjust to other sizes. Once the grading is completed, the sizes nest within one another and developing markers for cutting is easier, therefore reducing the time spent in pre-production (Jhanji, 2015). Proportion grading is most common in the industry due to its practicality and cost-effectiveness since it based on previously created body size tables (Petrova & Ashdown, 2012).

**Pant patterns and fittings.** Pants are one of the more difficult garments to fit based on the variety of heights and crotch depths. Pants are challenging for consumers to find the correct size and fit, and there had been limited research in terms of the virtual fit of pants (Eccles, 2011;
Kim & LaBat, 2013; Lee, Nam, Cui, & Choi, 2007; Piller, 2008; Song & Ashdown, 2013; Song & Ashdown, 2015). As established by Erwin (1949), the fit of a garment is based on ease, grain, line, balance, and set and how they interact, but traditionally fit is evaluated through the analysis of wrinkles, if the garment has enough material to wrap around the body (Erwin, 1949; Petrova & Ashdown, 2012). The foundation of a well-fitting garment begins with accurate pattern making, in which block patterns, like a template, are manipulated to create the desired look (Huang et al., 2011). An example of a 2D pant pattern block can be seen in Figure 6.

**Figure 5.** 2D pant pattern in Gerber Accumark Pattern Design software.

During the manipulation of block patterns, garment ease is added which is important in allowing the garment to be moveable and comfortable for the wearer (Huang et al., 2011; Petrova & Ashdown, 2011). Pants patterns are developed based on a few key measurements. They have different waistlines, lengths, and pant leg fitting (ie straight, boot cut, flare, etc). Technical designers within the industry are trained to use wrinkle analysis in various body positions and create alterations to reduce the fit issues (Petrova & Ashdown, 2012). Fitting within 3D software
programs is slightly different because draglines may not be as visible or noticeable, and it is more difficult to test crotch depth and seat.

**Female Body Types**

Body shapes have been related to the success of good fit in garments (Song & Ashdown, 2011). In previous studies, it was shown that women can have the same hip measurement but have a different body type (Song & Ashdown, 2011; Vuruskan & Bulgan, 2010), which is what makes it difficult to mass produce garments that fit. Women’s bodies can also change shape depending on weight loss or weight gain, but how a woman’s measurements change is dependent upon the individual (Simmons, Istook, & Devarjan, 2004).

There are many different terminologies used to describe women’s body shapes. They range from geometrical figures (rectangle, oval, triangle, ...), to letters (A, V, H, O, X...), to fruits and vegetables (pear, apple...), but many refer to the same figures based on front body silhouette (Vuruskan & Bulgan, 2010). There are different methods used to categorize female body shapes. The first method is drop values of body circumference measurements, ratios of body circumference, and PC and cluster analysis (Kim, Song, & Ashdown, 2016). In this research, the ratios of body circumference method will be used. Through previous studies, 9 different female body types have been classified based on bust, waist, and hip measurements. Some body shapes are determined by the front silhouette whereas others are based on ratios of measurements. Ratios of measurements are more related to fit since the bust, waist, and hip measurements are used for evaluation (Vuruskan & Bulgan, 2010). According to FFIT data (Simmons et al, 2004), the following body types as shown in Figures 7-13 have been classified based on certain body measurements.
Female Figure Identification Technique (FFIT). The main objective of developing the Female Figure Identification Technology (FFIT) software was so that it could identify the body shapes of women from 3D body scans and code the body shapes based on theoretical mathematical shape definitions (Simmons, Istook, & Devarjan, 2004). This was used to verify the data collected from 3D body scanning to determine women’s body shapes. It was also developed to create a new sizing system that would be effective and efficient (Simmons, Istook, & Devarjan, 2004). A set of shapes were defined with mathematical descriptors using the bust, waist, hip, stomach, and abdomen circumferences (Simmons, Istook, & Devarjan, 2004). It proved accurate in defining these shapes and to show basic sizing systems were not always the most accurate regarding fit.

Female figure body shapes.

Hourglass. In this shape, there is a very small difference between bust and hip circumferences. The bust-to-waist and hips-to-waist ratios are almost equal (Simmons et al., 2004) This shape can be seen in Figure 6.

Figure 6. Example of an Hourglass (Simmons, 2002, 104).
**Top hourglass.** The top hourglass is a subset of the hourglass category but has a larger bust circumference than hip circumference. The bust-to-waist and hips-to-waist ratios produce a significant waistline (Simmons et al., 2004).

**Bottom hourglass.** The bottom hourglass is also a subset of the hourglass category, however, in this shape, the hip circumference is larger than the bust circumference. Both the bust-to-waist and hips-to-waist ratios produce a significant waistline (Simmons et al., 2004). This shape is seen in Figure 7.

![Figure 7. Example of a Bottom Hourglass (Simmons, 2002, 107).](image)

**Spoon.** In the spoon shape, there is a larger difference in the circumference of the hips and bust, and the bust-to-waist ratio is less than the Hourglass. In this shape, the high hip-to-waist ratio is great (Simmons et al., 2004). This shape is seen in Figure 8.
Figure 8. Example of a Spoon (Simmons, 2002, 113).

**Rectangle.** In the rectangle shape, the bust and hip measurements are almost equal. Also, the bust-to-waist and the hip-to-waist ratio are low (Simmons et al., 2004) (Figure 9).

Figure 9. Example of a Rectangle (Simmons, 2002, 116).
**Diamond.** In the diamond shape, the average measurements of the stomach, waist, and abdomen are larger than the bust measurement (Simmons et al., 2004). This can be seen in Figure 10.

![Diagram of Diamond Shape](image)

**Figure 10.** Example of a Diamond (Simmons, 2002, 119).

**Oval.** The oval shape is defined by average measurements of the stomach, waist, and abdomen that are less than the bust measurement (Simmons et al., 2004). This can be seen in Figure 11.
**Figure 11.** Example of an Oval (Simmons, 2002, 121).

**Triangle.** The triangle shape is defined by a hip circumference that is larger than the bust circumference and the hips-to-waist ratio is small (Simmons et al., 2004). This can be seen in Figure 12.

**Figure 12.** Example of a Triangle (Simmons, 2002, 124).
**Inverted Triangle.** In the inverted triangle shape, the bust circumference is larger than the hips and the bust-to-waist ratio is small (Simmons et al., 2004)

**Summary**

Based on the reviewed literature, there is a need in the research to determine if 3D visualization can assist in developing mass customized garments based on body types. Mass customization has become a more popular option within the textile and apparel industry with many brands offering consumers more input on the fit and design of their garments. CAD technology is popular with industry due to improvement in some of the overall workflow for designers. Some of the software programs improve the speed of pattern making and fitting processes to help designers visualize the final look. Although these technology advancements are helpful to the industry, fit and sizing remains one of the larger challenges due to all the individualized body types.
CHAPTER THREE: METHODOLOGY

Research Questions

The following research questions were used to guide the research for 3D apparel visualization and fit based on body types:

1. Can 3D software programs be used to visualize the fit and design of pants?
   a. Is the ability to visualize the fit and design of garments influenced by job function?
   b. Are years of experience an influencing factor when evaluating fit from the 3D software simulation?

2. Of the three shapes studied (rectangle, oval, triangle), how does the body shape of the model impact virtual fit evaluation in 3D software programs?

3. Can a software generated avatar and an imported body scan avatar be evaluated equally when wearing the same pair of pants?

Research Design

The research tested whether better fitting garments could be developed based on body types versus general apparel sizing. Creating pants patterns based on the body type would allow for a slightly more customized fit for consumers. The research took part in two segments, with the first pertaining to body scanning, 3D software use, and pant pattern development. The second portion of the research involved the survey that required members of the industry to evaluate the fit of pants. An IRB application was submitted for each portion of the research, which provided details of the study and the data collection methods used since human participants were involved.
Part One

The first part of the study involved several steps. Female participants between the age of 18 to 35 were recruited to be body scanned and to have their body shapes determined. The recruitment materials can be seen in Appendix C. Three participants were selected based on their shape and garments were developed for each.

**Garment design.** A basic pant pattern was developed based on the ASTM Missy size 8 measurements. It was used as the base garment pattern for the other pant patterns that were developed. This base pattern is known as the Control in this study. The measurements used to develop the size 8 base pattern were from ASTM 5585-11, which can be seen in Appendix E.

**Body shape identification.** A total of four participants were recruited and body scanned. After evaluating the body scans, it was determined there were three different body types among the four women. The body types were determined from the measurements collected from the body scans and compared with the Female Figure Identification Technique Chart (Simmons & Istook, 2004) to determine each participant’s body shape.

**Body scanning.** A Size Stream SS20 scanner was used to collect the anthropometric data from the female participants. The measurements collected from the body scan formed a 3D point cloud image that was brought into the Size Stream Studio to be converted into a smooth avatar, which is known as an OBJ file. When preparing the body scan to become an avatar, the Preserve Landmarks morph target was selected to help with the measurement landmark and contour placement. This selection could have impacted how the measurements were given from the body scanner and why the initial measurement was not in the needed location. The OBJ files can be imported into 3D software programs to be used as an uneditable avatar. The body scans can be seen in Appendix D.
**FFIT for Apparel.** The Female Figure Identification Technique (FFIT) (Simmons & Istook, 2004) uses measurement comparisons to categorize nine different female body shapes. Four participants were scanned, and it was determined that two women were Rectangles, one was an Oval, and the other was a Triangle.

**Garment alteration.** Gerber Accumark Pattern Design was used to create and manipulate the pants patterns created for each body shape. A total of four pants patterns were developed. The pants for each body shape included: the Control, Rectangle, Oval, and Triangle. The objective was to develop pants patterns for each body type identified from a basic pant block to determine if body shape influences fit. The base pattern was developed from an existing ASTM Missy Block Patten. The pant leg was altered to be narrower than the initial block to appear more fitted by adjusting the front and back patterns to be approximately 8in at the leg opening. The pant block was compared with the ASTM size chart to confirm measurements were correct and grade points were added. When the first pattern was created, there were some fit issues with the pattern and the avatar measurements. The first round of prototypes performed in the 3D software proved to be much larger and was poorly draped on the avatars. The initial body scans were reviewed and it was determined that the body scanner did not align with the measurements needed to develop proper fitting pants. To extract the proper measurements, cross-sections of the scan were taken to determine the measurement was taken at the correct point. The cross-sections were taken at the waist, hip, high hip, and thigh. The measurements were extracted by using the Size Stream landmark and contour lines to select where the cross-section is to be taken. An example of the cross section that was taken can be seen in Appendix F.

A consistent ease was developed and used on all the patterns based on the difference between the Control Avatar and the Control Pattern. The Control Avatar was developed by adjusting the
CLO 3D stock avatar measurements to reflect the measurements from the ASTM missy size 8. The Control pant pattern was established to serve as a fit standard for the other pant patterns to be compared to and to reflect a similar fit. The amount of ease used for each pant can be viewed in Table 1. The image of the Control pattern can be viewed in Appendix A.

Table 1. Ease Chart (in inches) for Pants

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Control Avatar</th>
<th>Control Pattern</th>
<th>Ease Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist</td>
<td>26.5</td>
<td>27.328</td>
<td>0.828</td>
</tr>
<tr>
<td>High Hip</td>
<td>35.5</td>
<td>35.72</td>
<td>0.22</td>
</tr>
<tr>
<td>Hip</td>
<td>37.25</td>
<td>40.31</td>
<td>3.06</td>
</tr>
</tbody>
</table>

*Garment draping.* After the patterns had been manipulated in 2D, the files were imported into the CLO 3D software. Each of the pant patterns was aligned, virtually stitched, and arranged on each of the corresponding avatars.

*Avatar prep.* A software stock avatar was adjusted based on the measurements from the ASTM D5585 missy straight size 8 to represent the Control. A size 8 was selected because it is the base size in most pattern making software programs and has been used in previous studies as a base size (Kim & LaBat, 2013). Three CLO avatars were adjusted from the base size avatar to reflect the body measurements of the three participants. Although measurements of the avatar within CLO 3D can be adjusted, the user cannot specify where the measurement will be added regarding the width and depth of the avatar shape. Even with the avatar size adjusted, it cannot be precise due to the linked measurement editing feature. While working with these avatars, the user has limited ability to adjust the measurements before the avatar begins to appear flattened and disproportionate. The other three avatars were the imported OBJ files that were created from the body scans. These avatars cannot be adjusted, and directly reflect the smooth point cloud
version of the body scan. A total of seven avatars were created to establish reliability and validity, so the pants were tried on two models of the same body type, for a total of 1 control software avatar, 3 adjusted software avatars, and 3 body scan avatars. The dress form was not scanned and imported as an OBJ file to represent the Control because the dress form did not have human features like a head, arms, and hands making it difficult to scan. The measurements for each of the body shapes can be viewed in Table 2.

**Table 2.** Comparison Chart between Each Model (in inches)

<table>
<thead>
<tr>
<th></th>
<th>Dress Form</th>
<th>Control</th>
<th>Rectangle</th>
<th>Oval</th>
<th>Triangle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Pattern</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Chest/Bust Girth</td>
<td>35.5</td>
<td>35.5</td>
<td>39.91</td>
<td>39.18</td>
<td>36.84</td>
</tr>
<tr>
<td>Waist Girth – Straight</td>
<td>26.5</td>
<td>26.5</td>
<td>30.75</td>
<td>34.01</td>
<td>31.84</td>
</tr>
<tr>
<td>High-Hip Girth – Straight</td>
<td>35.5</td>
<td>35.5</td>
<td>35.8</td>
<td>39.39</td>
<td>37.18</td>
</tr>
<tr>
<td>Hip/Seat Girth – Straight</td>
<td>37.25</td>
<td>37.25</td>
<td>39.64</td>
<td>41.7</td>
<td>43.85</td>
</tr>
<tr>
<td>Thigh Girth – Straight</td>
<td>21.25</td>
<td>21.25</td>
<td>23.33</td>
<td>23.48</td>
<td>24.05</td>
</tr>
<tr>
<td>Crotch Height</td>
<td>30.5</td>
<td>30.5</td>
<td>29.75</td>
<td>31.99</td>
<td>31.16</td>
</tr>
</tbody>
</table>

**Fabric preparation.** In addition to collecting measurements from the human participants, fabric testing was performed as described in the next section. This testing was necessary because the fabric used in the physical prototype needed to be translated to a digital format that could be used within the CLO 3D software. The testing procedures established by CLO 3D determined the fabric weight and drape values to be input into the software program so that the digital fabric can closely mimic the physical fabric properties. The fabric was a 97% cotton and 3% spandex woven fabric that was used on the actual garment and in the 3D simulation.
CLO 3D Fabric Kit. The tests that were performed on the fabric were established by CLO 3D in their Fabric Kit. Three samples, 220mm by 30mm, were cut from the fabric (warp, weft, and bias) to perform the different types of tests. The swatch weight and thickness were taken. A bend test and stretch test were also performed to determine fabric drape and stretch. These tests were performed on instruments developed by CLO 3D. The bend test uses the weft and warp swatches to determine the contact distance and length at which the fabric begins to drape. The stretch test uses clamps and a gear to stretch fabric, while a digital force gauge is attached to the instrument to determine the force placed on the fabric when stretched. For a woven fabric, like the sample, the gauge was read at every millimeter up to 5 millimeters for kilogram-force (kgf).

The CLO 3D Fabric Kit that includes the tools used to perform the tests can be viewed in Figure 13. The data collected from the various tests and values entered in the CLO 3D Fabric Emulator can be viewed in Table 3.

![Figure 13](image-url)
After the data had been collected, the information was entered into the fabric emulator in CLO 3D. This emulator used the data to form a digital fabric that closely resembled the drape, stretch, and weight of the physical fabric.

### Table 3. Fabric Test Data from the CLO 3D Test Kit

<table>
<thead>
<tr>
<th>Fabric Name</th>
<th>Woven Stretch Khaki</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
<td>3.96 g</td>
</tr>
<tr>
<td><strong>Thickness</strong></td>
<td>0.36 mm</td>
</tr>
<tr>
<td><strong>Warp</strong></td>
<td>Contact Distance: 42 mm</td>
</tr>
<tr>
<td></td>
<td>Contact Length: 49 mm</td>
</tr>
<tr>
<td><strong>Weft</strong></td>
<td>Contact Distance: 16 mm</td>
</tr>
<tr>
<td></td>
<td>Contact Length: 29 mm</td>
</tr>
<tr>
<td><strong>Stretch</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Warp</strong></td>
<td>1. 1mm/0.06kgf</td>
</tr>
<tr>
<td></td>
<td>2. 2mm/0.21kgf</td>
</tr>
<tr>
<td></td>
<td>3. 3mm/0.458kgf</td>
</tr>
<tr>
<td></td>
<td>4. 4mm/0.830kgf</td>
</tr>
<tr>
<td></td>
<td>5. 5mm/1.415kgf</td>
</tr>
<tr>
<td><strong>Weft</strong></td>
<td>1. 1mm/0.018kgf</td>
</tr>
<tr>
<td></td>
<td>2. 2mm/0.03kgf</td>
</tr>
<tr>
<td></td>
<td>3. 3mm/0.04kgf</td>
</tr>
<tr>
<td></td>
<td>4. 4mm/0.05kgf</td>
</tr>
<tr>
<td></td>
<td>5. 5mm/0.06kgf</td>
</tr>
<tr>
<td><strong>Bias</strong></td>
<td>1. 1mm/0.010kgf</td>
</tr>
<tr>
<td></td>
<td>2. 2mm/0.018kgf</td>
</tr>
<tr>
<td></td>
<td>3. 3mm/0.024kgf</td>
</tr>
<tr>
<td></td>
<td>4. 4mm/0.029kgf</td>
</tr>
<tr>
<td></td>
<td>5. 5mm/0.034kgf</td>
</tr>
</tbody>
</table>

**Image collection.** In addition to data collected on the physical and tensile properties of the fabric, an image was taken of the fabric. The image will be used in the software program to show the fabric texture and be associated with the data entered in the fabric emulator. The photo was taken using a high-resolution camera and a special photo stand that can be seen in Figure 14.
The photo was edited in Photoshop to develop a pattern and normal map to form a texture for the virtual fabric in CLO 3D.

![Photo apparatus used to take a high definition photo of the fabric.](image)

**Figure 14.** Photo apparatus used to take a high definition photo of the fabric.

Images of the physical prototype and 3D models were also taken and used for the survey. The physical prototype was placed on a dress form and photographed from a front, side, and back view. The images of the 3D models within CLO were taken using image capture, which took a front side and back view for each avatar and OBJ model. These images can be viewed in Appendix B.

**Part Two**

In the second portion of the study, a survey was developed to analyze the fit of the different pants made for each body type. In the survey, images of the virtual garments were shown on the different avatars and various questions were asked about the fit and appearance of the pants on the different avatars.
Selection of Subjects. The survey was sent out to those currently or who have worked within the fashion and textile industry. These were known industry contacts provided by the advisor. Most participants work at companies such as Target, Under Armor, and Walmart. Each contact was emailed and provided the survey in the initial contact email.

Development of Survey. The survey was broken into four segments: participant background, experience with 3D apparel visualization software, fit analysis, and fit comparison. The survey questions were based on a visual analysis to determine if the garment fits properly by looking at how the pants drape on each avatar (Petrova & Ashdown, 2012). In segment 2, participants were also asked to rate their level of satisfaction using 3D software programs for prototyping. In section 3, participants were asked to rate the fit of an image showing a simulated garment. This was evaluated using the Likert scale method, and survey participants rated the fit of the pants on a scale of 1 to 5, with 1 being poor fit and 5 being the best fit. In section 4, participants were asked to select the better fit between the avatar and OBJ, and between the 3D Control and physical prototype. Qualtrics was used to develop the survey and collect the data. The full survey can be seen in Appendix G.

Survey Distribution. The survey was distributed through multiple platforms that included email, LinkedIn, and special interest groups. An email was sent to a list of industry members that was acquired by the research advisor based on known connections and previous contact before the research. The survey was sent with the initial contact email regarding the information about the survey. It was also asked that the survey be shared among co-workers and other industry connections. This data was collected online via Qualtrics. The initial email sent to the list of industry members can be viewed in Appendix B.
Data Analysis

Data was analyzed using R software. Before the analysis, survey questions were mapped to the research questions and appropriate statistical analysis methods for each subset of data were selected. The data source reflects the survey questions that were analyzed when performing the statistical analysis tests. The specific data variables represented the variables that were analyzed within the tests and relate to the research question. In table 4 there is an overview of the data analysis approach that specifies the research question, data source, variable, and statistical analysis.

Table 4. Summary of Methodology

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Data Source</th>
<th>Specific Data Variables</th>
<th>Statistical Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Can 3D software programs be used to visualize the fit and design of pants?</td>
<td>Q5, Q8, Q17</td>
<td>Pant fit rating, 3D software interest, 3D satisfaction (Q8 &amp; Q55 components)</td>
<td>T-Test, ANOVA, Paired T-Test</td>
</tr>
<tr>
<td>1a. Is the ability to visualize the fit and design of garments influenced by job function?</td>
<td>Q1, Q10, Q11, Q12, Q13, Q14, Q15, Q16</td>
<td>Job function, pant fit rating</td>
<td>One-way analysis of means, ANOVA</td>
</tr>
<tr>
<td>1b. Are years of experience an influencing factor when evaluating fit from the 3D software simulation?</td>
<td>Q3, Q10, Q11, Q12, Q13, Q14, Q15, Q16</td>
<td>Years of experience, pant fit rating</td>
<td>One-way analysis of means, ANOVA</td>
</tr>
<tr>
<td>2. Of the three shapes studied (rectangle, oval, triangle), how does the body shape of the model impact virtual fit evaluation in 3D software programs?</td>
<td>Q10, Q11, Q12, Q13, Q14, Q15, Q16</td>
<td>Body shape, pant fit rating</td>
<td>Hotelling’s, T-Test</td>
</tr>
<tr>
<td>3. Can a software generated avatar and an imported body scan avatar be evaluated equally when wearing the same pair of pants?</td>
<td>Q17, Q18, Q19, Q20, Q21</td>
<td>Avatar, OBJ, pant fit rating</td>
<td>Proportion Test, T-Test</td>
</tr>
</tbody>
</table>
CHAPTER FOUR: PRESENTATION OF DATA

This portion of the study was used to collect data on the perceptions of different body shapes and avatars using 3D visualization. The goal of the study was to take body shape into account when developing patterns, along with ASTM sizing, to determine a way to be more accurate and inclusive with sizing for women.

Description of Sample

The survey was sent to known connections and shared among industry members. A total of 35 participants completed the survey. Many participants were product designers and technical/pattern designers, but there were also marketers, merchants/buyers, and product developers (Figure 15). There was an “Other” category in which six people identified themselves as having a job within the 3D field. Most participants had experience within women’s bottoms/pants, women’s tops/outerwear, men’s bottoms/pants, men’s tops/outerwear, children’s wear, and fashion apparel accessories. Participants’ years of experience ranged from 1 year to over 15 years (Figure 16). All participants had some form of higher education in which 1 had an Associate’s degree, 32 had Bachelor’s degrees, and 2 had Master’s degrees. Participants had also worked within multiple product categories (Figure 17).

The participants’ background in 3D apparel visualization varied. Approximately 37% use 3D software programs frequently, 11% use it sometimes, 3% have used it in a previous position, 6% do not use it but the company is transitioning, and 43% do not use these tools. Most software programs that are used or have been previously used are Browzwear, CLO 3D, and Optitex.
**Figure 15.** Participants’ current job title.

**Figure 16.** Participants’ years of experience in the industry.
Figure 17. Participants’ product category experience.

Data Analysis

Research Q1: Can 3D software programs be used to visualize the fit and design of garments so that fewer prototypes are needed?

Although participants had varying opinions on how the 3D software programs should be utilized, all participants showed interest in using 3D virtual design software to visualize garments. Participants who use or have previously used 3D software programs were asked to complete questions relating to software usefulness and productivity. When asked if 3D programs assisted with prototyping 95% of participants agreed to some level, and when asked if the virtual garment was reflective of the final garment 85% agreed. The data collected indicates that the participants are interested in using 3D apparel visualization software to some degree and believe that it would help with the product development process. However, no strong conclusions can be
determined from the data to prove that fewer prototypes will be needed if 3D software programs are used.

The questions part of Q9 in Appendix G asked participants if they were interested in using 3D apparel visualization software and their overall level of satisfaction with using the programs. Participants were also asked to rate their level of satisfaction with 3D apparel visualization software regarding several topics. These included: prototype help, time reduction, time addition, 3D garment representation and realism, and accurate fit display. The results show that all participants were interested in using 3D software in some form, even though the intended use varied, which can be seen in Figure 18. When participants were asked if it helped with prototyping, 80% strongly agreed and 15% agreed. The participant’s level of agreement varied when asked if they felt it added time to the design process, reduced time in the design process, was the 3D garment representative of the final garment, and is fit reflected accurately. They were also asked if they felt the 3D simulated garment was representative of the final garment, 25% strongly agreed and 60% agreed. The results on the level of agreement can be viewed in Table 5.

Figure 18. Participant interest in how 3D tools should be utilized.
Participants were also asked to select how they think 3D software should be used and to rate their level of interest in overall use of technology, using it as a substitute for prototyping garments, the influence of body shape on the garment, and the influence of the software avatar and the body scan avatar (OBJ file). When asked about using 3D technology in the design and development process, 60% chose most interested and 31.43% chose interested. Participants were asked to rate from least to most if the body shape would influence rating of garment fit in which 28.57% rated a level 5 (most) and 31.43% rated a level 4. Participants were also asked how likely they were to use a software generated avatar and an avatar generated from a body scan. Based on the scale, more participants showed interest in using an avatar generated from a body scan. These questions and ratings can be viewed in Table 6.

### Table 6. Participant Input on 3D Apparel Visualization Utilization

<table>
<thead>
<tr>
<th>Questions</th>
<th>Least</th>
<th>2</th>
<th>Neutral</th>
<th>4</th>
<th>Most</th>
<th>Total</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>How interested would you be in using 3D technology for the design and development process for garments?</td>
<td>0%</td>
<td>0%</td>
<td>8.57%</td>
<td>31.43%</td>
<td>60%</td>
<td>35</td>
<td>4.51</td>
</tr>
</tbody>
</table>
Table 6. (Continued)

<table>
<thead>
<tr>
<th>Question</th>
<th>Percentage</th>
<th>(N)</th>
<th>Percentage</th>
<th>(N)</th>
<th>Percentage</th>
<th>(N)</th>
<th>Percentage</th>
<th>(N)</th>
<th>Percentage</th>
<th>(N)</th>
<th>Percentage</th>
<th>(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How likely would you be to use 3D apparel visualization tools as a substitute for prototyping of garments?</td>
<td>8.57%</td>
<td>(3)</td>
<td>17.14%</td>
<td>(6)</td>
<td>8.57%</td>
<td>(3)</td>
<td>25.71%</td>
<td>(9)</td>
<td>40%</td>
<td>(14)</td>
<td>35</td>
<td>3.71</td>
</tr>
<tr>
<td>How does the shape of the avatar influence your rating of garment fit?</td>
<td>11.43%</td>
<td>(4)</td>
<td>8.57%</td>
<td>(3)</td>
<td>8.57%</td>
<td>(3)</td>
<td>42.86%</td>
<td>(15)</td>
<td>28.57%</td>
<td>(10)</td>
<td>35</td>
<td>3.69</td>
</tr>
<tr>
<td>How likely would you be willing to use a 3D avatar generated by the software program?</td>
<td>2.86%</td>
<td>(1)</td>
<td>17.14%</td>
<td>(6)</td>
<td>28.57%</td>
<td>(10)</td>
<td>31.43%</td>
<td>(11)</td>
<td>20%</td>
<td>(7)</td>
<td>35</td>
<td>3.49</td>
</tr>
<tr>
<td>How likely would you be willing to use a 3D avatar generated from a body scan?</td>
<td>2.86%</td>
<td>(1)</td>
<td>2.86%</td>
<td>(1)</td>
<td>5.71%</td>
<td>(2)</td>
<td>42.86%</td>
<td>(15)</td>
<td>45.71%</td>
<td>(16)</td>
<td>35</td>
<td>4.26</td>
</tr>
</tbody>
</table>

Q1A. Is the ability to visualize the fit and design of garments influenced by job function? Participants rated each pair of pants created for all three body shapes and the control. They were asked to rate the pants on a scale of 1 to 5, with 1 being the worst and 5 being the best fit. When completing the survey, they were also asked to list their current job function. Each job title was compared to the score that was given to each of the seven pairs of pants to determine if the job function plays an influential role in how scores are given. There were initially six job functions, but six out of the eleven “Other” responses involved a job function with 3D, therefore it was reorganized to show seven job functions. The seven job functions are categorized as Marketing, Merchant/Buyer, Product Design, Product Development, Technical/Pattern Design, 3D, and Other (Retired). The job function distribution can be viewed in Figure 15.

A one-way analysis of variance was used to compare the means across all job functions to determine if job function was influential in determining the fit rating. The test showed the results were not significant and therefore could not prove job function impacted the fit rating. The sample pool for each job function varied, and some were too small to have conclusive results. This can be viewed in Figure 19. An ANOVA test was run to compare job function with
the rating of the Avatar and the OBJ. For both the Avatar and the OBJ, the results were not significantly different, and more data is needed due to the smaller groups of respondents within each job function, therefore it cannot be proven that the job function influences pant fit rating. These results can be viewed in Figures 20 and 21.

**Figure 19.** Overall pant fit rating per job function.

**Figure 20.** Avatar pant fit ratings by job function.
Q1B. Are years of experience an influencing factor when evaluating fit from the 3D software simulation? Survey respondents were also asked to give their years of experience working in the fashion and textile industry. The years of experience was another variable that was compared to the rating of each pair of pants to determine if it would influence the score that was given for fit. Years of experience were categorized into five groups: 1-3 years, 4-6 years, 6-10 years, 10-15 years, and 15+ years. The years of experience distribution can be viewed in Figure 22. A one-way analysis of variance was run to compare the fit rating of each pant with the years of experience. When comparing the overall rating of both the Avatar and OBJ with years of experience, there was no significant difference between the varying years of experience and rate that was given. The results can be seen in Figure 23.
An ANOVA test was used to compare the Avatar ratings against years of experience, as well as the OBJ ratings. This allowed for each year of experience category to be compared against the ratings of the pants, in which the years of experience were the dependent variable and the rating was the independent variable. For both the Avatar and the OBJ, the results were not
significantly different and more data is needed, therefore it cannot be proven that years of experience influence pant fit rating. These results can be viewed in Figures 24 and 25.

**Figure 24.** Avatar pant fit ratings by years of experience.

**Figure 25.** Body scan (OBJ) pant fit ratings by years of experience.

**Research Q2:** Of the three shapes studied (rectangle, oval, triangle), how does the body shape of the model impact virtual fit evaluation in 3D software programs? Four pant patterns were developed and placed on an avatar and an OBJ model. Each pant pattern was
evaluated based on the avatar and the OBJ model. These fit ratings for each of the 3 body shapes and the control were compared against each other in multiple ways to determine if the body shape influences fit. When comparing fit averages for each body type, among the Avatars the Control had the highest average followed by the Oval, Rectangle, and then Triangle. There was not an OBJ available for the Control since it was developed from the ASTM D5585-11 Missy sizing chart. When comparing the averages among the three body shapes the Rectangle had the highest score, followed by the Triangle and then the Oval. The average pant fit rating for each body shape can be seen in Table 7.

**Table 7. Pant Fit Rating for Each Body Shape**

<table>
<thead>
<tr>
<th>Body Shape</th>
<th>Avatar Mean</th>
<th>OBJ Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle</td>
<td>2.89</td>
<td>3.09</td>
</tr>
<tr>
<td>Oval</td>
<td>2.91</td>
<td>1.46</td>
</tr>
<tr>
<td>Triangle</td>
<td>1.66</td>
<td>1.69</td>
</tr>
<tr>
<td>Control</td>
<td>3.46</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note: The rating scale was from 1-5, 1 being the worst and 5 being the best.

A Hotelling’s test was run to compare multivariate data from the differences of mean fit rating scores for each of the three body shapes and the two avatars. When comparing body shapes in the Avatar form, there were significant differences found when comparing the Rectangle versus Triangle and the Oval versus the Triangle. When comparing in the OBJ form, Rectangle versus Oval and Rectangle versus Triangle had a significant difference. The comparisons can be seen in Table 8.
Table 8. Mean Pant Fit Rating Comparison for Each Body Shape

<table>
<thead>
<tr>
<th>Comparison</th>
<th>T-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle vs. Oval Avatar</td>
<td>0.015</td>
<td>0.905</td>
</tr>
<tr>
<td>Rectangle vs. Triangle Avatar</td>
<td>52.564</td>
<td>0.00000002159*</td>
</tr>
<tr>
<td>Oval vs. Triangle Avatar</td>
<td>26.606</td>
<td>0.00001071*</td>
</tr>
<tr>
<td>Rectangle vs. Oval OBJ</td>
<td>92.363</td>
<td>0.00000003194*</td>
</tr>
<tr>
<td>Rectangle vs. Triangle OBJ</td>
<td>71.988</td>
<td>0.0000006566*</td>
</tr>
<tr>
<td>Oval vs. Triangle OBJ</td>
<td>2.572</td>
<td>0.118</td>
</tr>
</tbody>
</table>

Note. * is significant at p<.05 level.

When each body shape Avatar was compared against the Control Avatar all showed a significant difference when comparing the mean for each of the body shapes fit ratings. The body shape and control comparisons can be viewed in Table 9. This test indicates that body shapes were not rated the same, therefore the shape and model type influenced the fit rating.

Table 9. Pant Fit Rating Comparison for Each Body Shape Avatar Against the Control.

<table>
<thead>
<tr>
<th>Control Comparison</th>
<th>T-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle v. Control</td>
<td>6.018</td>
<td>0.0195*</td>
</tr>
<tr>
<td>Oval v. Control</td>
<td>7.203</td>
<td>0.0112*</td>
</tr>
<tr>
<td>Triangle v. Control</td>
<td>71.933</td>
<td>0.00006624*</td>
</tr>
</tbody>
</table>

Note. * is significant at p<.05 level.

Research Q3: Can a software generated avatar and an imported body scan avatar be evaluated equally when wearing the same pair of pants? The testing done in the first part of the study uses avatars and body scans as models within the 3D software programs. Some survey questions asked participants to pick between the avatar and the OBJ version of each body shape. Based on averages, there was a mix between the Avatar and OBJ preferences. The
averages can be viewed in Table 7. A T-Test was used to compare the two variables of the Avatar average against the OBJ average. The test yielded a significant figure showing preference towards the Avatar. There was a preference towards the avatar native to the software, which could have caused bias in the pant fit ratings, but more research would be needed to investigate further as to if and how the avatars influence the opinion of the fit.

Individual fit ratings were taken for each pant that represents the shape on the software avatar and the imported body scan. The fit ratings varied among the two different models. The comparison between the avatar and OBJ model for each body shape showed more people selected the avatar, which can be viewed in Table 10. When asked if the body shape would influence the opinion of fit, 28.57% said most likely and 31.43% said likely. Participants were asked about their likeliness to use a software generated avatar and a body scan generated avatar. When asked about the software avatar 17.14% rated interest at 2 (not likely), 28.57% were neutral, 31.43% rated interest at 4 (likely), and 20% rated a 5 (most likely). When asked to rate their level of interest in using a body scan avatar, 5.71% were neutral, 42.86% selected likely, and 45.71% selected most likely. More participants showed interest in using the body scan generated avatar, or the OBJ model. Participants were asked to select the better fit between the two variables: Avatar and OBJ model. The variables were compared and evaluated using a Proportions test. The results show that there is a significantly greater preference towards the Avatar over the OBJ with a P-value of 0.000000000006841. Another T-Test was used to evaluate the mean score from the respondent’s likeliness to use a software generated avatar against the mean score from the body scan avatar. When comparing the average scores from the two models, the test showed a significant preference towards the body scan with a P-value of 0.0004113. The avatar preferences, when compared with fit ratings, are contradictory because
participants indicated likeliness in using a body scan yet gave higher ratings to the avatar in separate questions from the survey.

**Table 10.** Participant Preference Selection Between the Avatar and OBJ for Each Body Shape

<table>
<thead>
<tr>
<th>Body Shape</th>
<th>Avatar</th>
<th>OBJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle</td>
<td>48.57% (17)</td>
<td>51.43% (18)</td>
</tr>
<tr>
<td>Oval</td>
<td>85.71% (30)</td>
<td>14.29% (5)</td>
</tr>
<tr>
<td>Triangle</td>
<td>97.14% (34)</td>
<td>2.86% (1)</td>
</tr>
<tr>
<td>Control</td>
<td>82.86% (29)</td>
<td>17.14% (6) *</td>
</tr>
</tbody>
</table>

Note: * There was no OBJ of the Control, only a physical garment on a dress form.

**Research Summary**

Several statistical tests were run for the research questions in the study. From the statistical testing, it could not be determined that job function or years of experience influenced the virtual fit evaluation. It was determined that body shape and avatar type can influence virtual fit evaluation. Some body shapes had a higher fit rating when compared to fit ratings for the other body shapes. There were also direct comparisons between avatars wearing the same pants in which participants preferred the software generated avatar over the body scan generated avatar.
CHAPTER FIVE: DISCUSSION, IMPLICATIONS, & RECOMMENDATIONS

There have been many innovations with tools, machinery, development, and production. The literature review noted advancements, as well as issues within the fashion and textile industry. Companies in the industry are using more technology to help reduce time and waste during the development process. Some of this technology includes incorporating 2D and 3D technology into the design and development of garments. 3D apparel visualization is one of the newer technologies that is used, so it is one that requires further advancements. It allows the 2D pattern to be virtually sewn and larger fit issues can be addressed. A consistent issue within the industry is the dissatisfaction with the fit of clothing, especially pants. There is a total of nine identified body shapes for women, and there is variation in sizes even within the body shape. Since there are so many body variations, it makes it difficult to mass customize pants that will work for everyone.

The purpose of the research was to study 3D virtual fit technology to analyze patterns created for women’s body types. After using three different body shapes to develop pants, it was determined that pants cannot be made in the same way for each body shape. Although the pant sizing was dependent upon the model’s size, the same ease amount was used among all pants. However, the pants did not fit the same for all despite using the same amount of ease. The ease amount and where ease is distributed could be influential in impacting the fit of pants for each body shape, but further research would be needed. It is important to begin incorporating other sizing systems besides traditional methods so that it can be inclusive to more body types. In the study, it was determined that 3D visualization software can be used to provide garment fit evaluation. With 3D technology, it will allow designers and others in the industry to make
garments at a faster rate due to the benefits of identifying major fit issues, reducing the need for multiple prototypes, and reducing time spent in the product development phase.

**Discussion of Results**

**Discussion of Pant Development for Body Shapes**

For the first portion of the research, pants were developed for three different body shapes based on a control pattern design. Participants were body scanned and the anthropometric measurements from the subjects were compared with the FFIT (Simmons et al, 2004) chart to determine body shape. OBJ body scan data and measurements were collected using a three-dimensional body scanning device. More companies are using these devices to determine sizing systems for their target market (Song & Ashdown, 2013). These devices can reduce the amount of time that it would normally take to get measurements. During the research process, a few issues were encountered. Cross-sections of the avatars had to be taken since the measurements provided from the body scan were not at the needed location to develop the pants. After the adjustment to the patterns had been made there was a visible improvement in how the pants draped on the avatars and fit closer to the waist. The patterns and software avatars were adjusted to reflect the updated measurements. With the correct measurements, the fit of the pants for each body type improved significantly. The body scans were converted into avatars and imported into the CLO 3D pattern making software program.

Since there is no standard sizing system used by apparel brands, the ASTM sizing standard for Misses (ASTM-D 5589) size 8 was used for the control garment in this research. The fit of clothing is an important element in determining the quality and consumer satisfaction, but it is difficult to determine because fit is both an objective and subjective analysis depending on the individual consumer’s perception (Song & Ashdown, 2010). Participants were asked to
rate the fit of the pants for each body shape and model. The pants were rated differently due to
the varying body shapes and fit on each model, which shows that fit can be difficult to
determine. The missy size 8 size that was selected as the base pattern could have also been
influential in impacting the fit of garments. The size of the garment is dependent upon body
shape, but it is difficult to determine consistent ease that will create a similar fit for all body
shapes. Ease allowance is determined during the fitting of the garment and influences pattern
grading and size development because different body sizes require different amounts of ease
(Bye et al., 2008; Petrova & Ashdown, 2012; Wang and Huang, 2011; Zhang, Innami, Kim,
Takatera, 2015). Since body sizes require different eases, there is potential that each body shape
could have different amounts of ease.

Pants were selected for the research because they are one of the more challenging
garments to fit due to the various crotch depths and lengths. Pants are challenging for consumers
to find the correct size and fit, and there had been limited research in terms of the virtual fit of
pants (Eccles, 2011; Kim & LaBat, 2013; Lee, Nam, Cui, & Choi, 2007; Piller, 2008; Song &
Ashdown, 2013; Song & Ashdown, 2015). Due to the limited research on the virtual fit of pants
and development based on body shapes, pants were developed for each of the three body shapes
identified. The fit average was relatively low for pant types for each of the body shapes, so
further research and prototypes would be needed to improve the fit. This would likely require
further manipulation of the basic pant block, specific ease for each body shape, and a physical
prototype to confirm fit.

**Using Software Avatars and Imported Body Scans**

With the advancements of 3D apparel visualization technology, more of the textile and
apparel industry are beginning to incorporate this software into their development process. These
programs allow designers to visualize the final garment by selecting fabric, color, textures, and some drape (Fontana et al., 2005 a,b; Jhanji, 2015). According to previous research, the use of 3D virtual fitting technology allows for fewer physical prototypes to be developed, reduces time to design and develop prototypes, and lowers production costs (Power, 2012; Salmon, 2014; Song & Ashdown, 2015). Although this software is helpful, physical prototypes are still needed to determine smaller fit issues due to the inability to show small folds, slight tightness or looseness, and stress folds (Song & Ashdown, 2015). This was evident in the research as there were strong similarities in the 3D Control garment and the physical prototype, but smaller draglines and fit issues were more visible in the physical prototype.

Within the software program, avatars are used as a tool to reflect human body measurements and to display the pattern and drape of the fabric. Avatars can be created by importing a 3D body scan or OBJ file, or by adjusting the parametric model’s body measurements (Song & Ashdown, 2015). Parametric models generally come as part of the software system and many measurement locations on the avatar can be adjusted to reflect the human model’s measurements. However, the OBJ files output directly from the body scan so it cannot be adjusted for shape or movement, without a significant amount of effort. During this research, the true limitations of the parametric model within the 3D software program were discovered. In other studies, researchers determined that the parametric model varied from the actual body shape and contained different dimensions than the model created from the 3D body scan (Lim & Istook, 2011; Song & Ashdown, 2015).

In this study, some of the avatar’s measurements could be adjusted, but many of the body proportions contain linked editing. This means that if one area of the body was adjusted other areas were also adjusted. The user could not specify how the measurement was added to the
avatar. The avatar and the human might share the same numerical body measurements, but those measurements were not necessarily controlled in the same way as shown on the body. For example, the avatar may have a 34” inch waist that is added in the stomach and back, whereas the human has a 34” waist that is wider at the hips or side of the body. Within CLO 3D, if the body was adjusted past a certain measurement, the avatar face would become flattened and deformed. While the face might be relatively unimportant to the evaluation of the fit of a garment on a body, it does indicate that there are likely more underlying issues that might be apparent.

Based on the survey, job function and years of experience were not an influencing factor in determining the fit rating, but body shape and avatar type were. In this survey, more participants were interested in using the OBJ avatar file obtained from body scanning versus using the avatar from the software system. After seeing the final results, more participants gave a higher fit rating for the garments on the software generated avatars. In the direct comparison, almost all the participants preferred the fit of the garment on the avatar over the OBJ model. The avatars created from the body scans (OBJ files) are more representative of the actual human body. Although there is no current reason as to why there was a preference for avatars, there are some possible explanations. The appearance of the software generated avatar has a smoother body mesh so the garment may have appeared to fit better compared to the actual human body shape reflected in the OBJ file. Another influencing factor is that the software avatar appeared more like a real person with hair and a face, whereas the OBJ file appears more like a mannequin. An image of the software generated avatar and the OBJ avatar of the same body shape can be viewed in Figure 26. Further research would be needed to understand why
participants preferred the software avatar over the OBJ avatar since the measurements and pants were the same for both models yet received different scores.

![Avatars with the same pants](image)

**Figure 26.** Avatars with the same pants: software generated (Left) & body scan/OBJ (Right).

**Research Questions**

The research questions were used as guidelines when developing the survey questions. The researcher wanted to know if job function and years of experience could be influencing factors in the fit rate score and if any correlation could be determined. The goal in developing the pants was to have it as a prototype not as a final garment so fit could be more easily evaluated. Due to the smaller sample size and different job function options, it was not possible to determine if the job function influenced the fit rate score given by the participant. The statistical analysis could also not determine if years of experience influenced the fit evaluation of the pants. More participant data or fewer job function and years of experience options would be needed to make further conclusions if these factors influence fit evaluation.
When comparing between body shapes, most showed some significant difference when comparing mean fit ratings, except for the Rectangle versus Oval Avatar and Oval versus Triangle OBJ despite having the same ease amount. When comparing the Avatar body shapes to the Control, all showed a significant difference when comparing the mean fit rating score. This information indicates body shape is an influencing factor in how fit is rated, and that each body shape is not evaluated the same.

Participants indicated in a survey question they would rather use the body scan avatar, yet in the fit evaluations gave software generated avatars higher scores. There are two potential explanations. One might be that the normalized shape of the software Avatar looked more attractive (like it fit better) than the real shape provided by the OBJ file. The second explanation is that the appearance of the body wearing the garment might impact the fit evaluation. The software avatar looked more like a real person (with a face and hair) than the OBJ file provided from body scanning. Further research would be needed to investigate if and how the avatars influence the opinion of the fit.

**Recommendations for Future Research**

If further research is to be continued, below is a list of recommended future research topics:

- Use a larger sample size since only 4 participants were body scanned and 3 were selected.
- Use other body shapes since only 3 of the 9 were used in the research.
- Incorporate other garments like tops, coats, undergarments, etc. because pants were the only garment tested.
- Use other categories (men’s, kid’s) since the study was only based on women’s sizing and apparel.
• Try different 3D apparel visualization software technology since only CLO 3D was used.
• Develop pattern eases for each body shape to see if it will improve the fit of the pants.
• Cut and sew physical prototypes for each virtual garment that is developed as an additional form of comparison since only one physical garment was created (the Control).
• Further investigate why more people preferred the software avatar over the OBJ.

Conclusions

In conclusion, more research will be needed to determine the overall improvement of the fit of pants. In conclusion, more research will be needed to determine the overall improvement of the fit of pants. It was determined that pants do not fit the same for all body types despite using the same ease amount and manipulating the same basic block. If basic blocks were adjusted to body shapes it could help improve the fit of garments and make garment adjustments easier for style and design purposes (Huang et al, 2011). In addition to creating basic blocks for body shapes, each body shape would need its own ease and applied in different areas depending on the body shape.

Fit can be evaluated using 3D software technology. How fit is evaluated in the software is dependent upon the evaluator’s perceptions despite the job function and years of experience that the individual may have. The body shape and avatar type can influence how fit is perceived and evaluated. Each body shape received a different score despite wearing pants that were adjusted specifically for that model’s measurements. More people prefer the software generated avatar because higher fit ratings were given. In the direct comparison portion of the survey (Q18-Q21), both avatars of the same body shape were wearing the same pants, and the software generated avatar was consistently chosen among all body shapes.
The industry is transitioning to 3D apparel visualization software. More people are beginning to classify 3D as a new job category or specialization separate from current positions in industry, such as technical pattern designer or CAD designer. Although more advancements of this technology are needed, the industry is moving to incorporate more of this technology in the development process.
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Appendix A: Pattern Images
Appendix B: Final Garments

Control-Physical Garment
Control-Avatar
Rectangle-Avatar
Rectangle-OBJ
Oval-Avatar
Oval-OBJ
Appendix C: Participant Recruitment and Communication

Participant Recruitment Poster

Body Type Mass Customization Study

Are you a female between 18-30 years old?

You are needed to participate in a body type mass customization study. Your participation would be a great help to my research!

For more questions, contact Peyton Hartis at plhartis@ncsu.edu
Body Scan Recruitment Email Announcement:

In our continued effort to use developing technologies to provide better fitting clothing, we are conducting a study to refine customization efforts for clothing. We are in need of Females age 18-30 for a “Body Type Mass Customization” study. We are looking for women with a variety of body shapes and especially those who might have problems finding garments that FIT. We will body scan all volunteers and will provide a printout with an image of body point cloud and a list of measurements. We will select 4 women with unique body shapes to continue with our garment development study. The selected subjects who are representative of these body types will be needed to model the sample garments developed. For more information and to sign up for the study, contact Peyton Hartis at phartis@ncsu.edu.

Body Scan Participant Consent Form:

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study/Repository: 3D Apparel Visualization technology utilizations for mass customized garments based on body types. (15470)
Principal Investigator: Peyton Hartis, phartis@ncsu.edu, 910-431-1827
Faculty Point of Contact: Dr. Cynthia Istook, cistook@ncsu.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate and to stop participating at any time without penalty. The purpose of this research study is to gain a better understanding of how 3D apparel visualization technology can be used to develop better fitting garments based on a consumer’s body type.

You are not guaranteed any personal benefits from being in this study. Research studies also may pose risks to those who participate. You may want to participate in this research because it can benefit future consumers in regards to fit of garments. You may not want to participate in this research because it will take some of your time to attend fit session meetings to analyze measurements.

In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above or the NC State IRB office (contact information is noted below).

What is the purpose of this study?
The purpose of the study is to gauge the fit accuracy of garments throughout the prototype stages of production in relation to virtual garments versus actual garments. Different patternmaking software will be used to determine the differences between 2D and 3D software, in addition to time used to develop the products, and accuracy of the garment fit based on different body types.

Am I eligible to be a participant in this study?
There will be approximately three participants in this study. In order to be a participant in this study you must identify as a female and be between the ages of 18 and 30 years old. You must also be able to provide your own transportation to and from fit session meetings located at the Wilson College of Textiles.
You cannot participate in this study if you identify as a male and are younger than 18 years of age or older than 30 years of age.

**What will happen if you take part in the study?**
If you agree to participate in this study, you will be asked to do all of the following:
1. Subjects who contact me and are interested will first have to sign a participant consent form and photo consent form.
2. The subject will then be scanned for measurements using the 3D body scanning technology located in the Wilson College of Textiles. The subject will be assigned a number so the body scanning data can not easily be traced to the subject for those who are not working on the study. When the subject is being scanned, she will be required to wear tight fitting garments (i.e. leggings and a sports bra) behind a closed curtain room during the scanning process for privacy and scanning accuracy. The 3D Image (avatar) does not show facial features and is generally considered unidentifiable.
3. After the measurement data is collected, the measurements will be organized into the 3 main body type groups.
4. One model will be selected to fit within each of the 3 categories.
5. Using avatars from the selected models, 3D garments will be designed and fitted, and then created into 2D patterns.
6. The patterns will be made into garments after the 3D fit evaluation for models to try on.
7. The fit models will be asked to try on the sample garments developed from the 3D and 2D pattern making technologies. This process will take 15 - 20 minutes for a maximum of three meetings total to analyze the measurements and fit of the garment.
8. Photos will be taken to compare the 3D garment on the avatar to the real garment on the model. Models' heads will be removed from the photos.

The total amount of time that you will be participating in this study is approximately an hour based on the total amount of fit meetings to analyze garment fit.

**Photos and video**
If you want to participate in this research, you must agree to being photographed. Your name and identity will not be associated with the photo as your face will be cut out of the image. If you do not agree to being photographed you cannot participate in this research.

As a part of this research, we would like your consent to <video record and/or audio record> your.

___ I consent to be photographed.
___ I do not consent to be photographed.

**Risks and benefits**
There are minimal risks associated with participation in this research. There are no direct benefits to your participation in the research. The indirect benefits are you will be assisting in a study that could potentially improve the fit of mass customized garments.

**Right to withdraw your participation**
You can stop participating in this study at any time. In order to stop your participation, please contact Peyton Hartis at plhartis@ncsu.edu stating that you wish to no longer participate in the study. If you choose to withdraw your consent and stop participating you can expect to no longer be contacted and have your information deleted from the study.

**Confidentiality**
The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely on an NC State managed computer. The data will be collected electronically through spreadsheets and the garment images will be taken with my personal phone camera and moved immediately to a password protected Google Folder as a digital file. The data collection will take place during the day 8-5, Monday through Friday (depending on subject availability) at the Wilson College of Textiles in either studio 1115 or studio 3412. The data
will be collected by me (the primary researcher), and will be shared with my advisors. ___ Unless you give explicit permission to the contrary, no reference will be made in oral or written reports which could link you to the study.

**Compensation**
For participating in this study you will not receive compensation. If you withdraw from the study prior to its completion, you will not be affected.

**Emergency medical treatment**
If you are hurt or injured during the study session(s), the researcher will contact the University’s emergency medical services at 1.919.515.3333 for necessary care. There is no provision for compensation or free medical care for you if you are injured as a result of this study.

**What if you are an NCSU student?**
Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

**What if you are an NCSU employee?**
Participation in this study is not a requirement of your employment at NCSU, and your participation or lack thereof, will not affect your job.

**What if you have questions about this study?**
If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the researcher, Peyton Hartis, plhartis@ncsu.edu, and 910-431-1827.

**What if you have questions about your rights as a research participant?**
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB (institutional Review Board) Office via email at irb-director@ncsu.edu or via phone at 1.919.515.8754. You can also find out more information about research, why you would or would not want to be a research participant, questions to ask as a research participant, and more information about your rights by going to this website: [http://go.ncsu.edu/research-participant](http://go.ncsu.edu/research-participant)

**Consent To Participate**
“I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled.”

Participant’s printed name ________________________________

Participant's signature ________________________________ Date ______________

Investigator's signature ________________________________ Date ______________
Survey Recruitment Email Announcement:

Hello,

My name is Peyton Hartis and I am a Master of Science Student at NC State Wilson College of Textiles. I am conducting research on the use of 3D apparel visualization software to evaluate the fit of pants and how different body shapes might influence fit evaluation. The results of this research will be presented in my final thesis paper.

We know that you or your company is exploring 3D Design technologies within your apparel product development, buying or merchandising units. We are looking for participants within the textile and apparel industry who have a variety of job functions that relate to apparel product development. The survey has a few images of 3D garments for review and can be taken online in less than 10 minutes. No personal information will be gathered other than job function and experience. The outcome of this study may help us better understand some of the variables that impact potential use of the technology.

Please share this survey with others in the industry who would be interested in evaluating images of 3D apparel fit. If you would like to know the findings of this survey, send an email to the researcher (phartis@ncsu.edu) to be added to the list of those interested in the final thesis publication.

Take the survey here: [https://ncsu.qualtrics.com/jfe/form/SV_09bBAFFp81rirUd](https://ncsu.qualtrics.com/jfe/form/SV_09bBAFFp81rirUd)

Thank you!

Peyton Hartis

Survey Recruitment LinkedIn Announcement:

I am a Master of Science Student at NC State Wilson College of Textiles. I am conducting research on the use of 3D apparel visualization software to evaluate the fit of pants and how different body shapes might influence fit evaluation. The results of this research will be presented in my final thesis paper.

We are looking for participants within the textile and apparel industry who have a variety of job functions that relate to apparel product development. The survey has a few images of 3D garments for review and can be taken online in less than 10 minutes. No personal information will be gathered other than job function and experience. The outcome of this study may help us better understand some of the variables that impact potential use of the technology.

Please share this survey with others in the industry who would be interested in evaluating images of 3D apparel fit. If you would like to know the findings of this survey, send an email to the researcher (phartis@ncsu.edu) to be added to the list of those interested in the final thesis publication.

Take the survey here: [https://lnkd.in/eWv6ECF](https://lnkd.in/eWv6ECF)
Appendix D: Body Scans
## Appendix E: Measurement Charts

### ASTM D585-11 Body Measurement Chart

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<th>04</th>
<th>06</th>
<th>08</th>
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<th>14</th>
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*Note: All measurements are in inches.*
## MISSY GRADE RULE CHART FOR PANT MEASUREMENTS (in inches)

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<th>6gr</th>
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<th>12gr</th>
<th>14gr</th>
<th>16gr</th>
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<td>1.125</td>
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<td>1.5</td>
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<td>1.75</td>
<td>1.875</td>
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<td>1</td>
<td>1.5</td>
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<td>1</td>
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<td>1.75</td>
<td>2.12</td>
</tr>
<tr>
<td>Hip/Seat Girth – Curvy</td>
<td>0.62</td>
<td>1.25</td>
<td>1.25</td>
<td>1.125</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.75</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Hip/Seat Girth – Straight</td>
<td>0.62</td>
<td>1.25</td>
<td>1.25</td>
<td>1.125</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.75</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Thigh Girth – Curvy</td>
<td>0.37</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.875</td>
<td>0.875</td>
<td>1.375</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Thigh Girth – Straight</td>
<td>0.37</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.875</td>
<td>0.875</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Mid-Thigh Girth – Curvy</td>
<td>0.37</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.875</td>
<td>0.875</td>
<td>1</td>
<td>1.125</td>
<td>1.12</td>
</tr>
<tr>
<td>Mid-Thigh Girth – Straight</td>
<td>0.37</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.875</td>
<td>0.875</td>
<td>1</td>
<td>1.125</td>
<td>1.12</td>
</tr>
<tr>
<td>Knee Girth</td>
<td>0.12</td>
<td>0.25</td>
<td>0.375</td>
<td>0.375</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Calf Girth</td>
<td>0.12</td>
<td>0.25</td>
<td>0.375</td>
<td>0.375</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Ankle Girth</td>
<td>0.12</td>
<td>0.125</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
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</tr>
<tr>
<td>Center Back Waist Length</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
</tr>
<tr>
<td>Center Front</td>
<td>0.12</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
<td>0.125</td>
</tr>
<tr>
<td>Waist Length</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Side Waist Length</td>
<td>0</td>
<td>-0.125</td>
<td>-0.125</td>
<td>-0.125</td>
<td>0</td>
<td>-0.125</td>
<td>0</td>
<td>-0.125</td>
<td>-0.125</td>
<td>0</td>
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</tr>
<tr>
<td>Crotch Length (total)</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.375</td>
<td>0.375</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>
Appendix F: Cross Section

Oval cross section at waist
Appendix G: Survey

3D Apparel visualization technology fit utilizations for garments based on body types.

Informed Consent Form

Title of Study: Evaluation of 3D Virtual fit of pants based on body type (eIRB # 20282)
Principal Investigator: Peyton Hartis
Funding Source: None
Faculty Point of Contact: Cynthia Istook (919) 515-6584

What are some general things you should know about research studies? You are invited to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate, and to stop participating at any time without penalty. The purpose of this research study is to gain a better understanding of the impact of body shape in the evaluation of fit using 3D Virtual Design software. We will do this by asking you to participate in an online survey. You are not guaranteed any personal benefits from being in this study. Research studies also may pose risks to those who participate. You may want to participate in this research because your response may help the industry have a better understanding of the issues impacting the use of 3D technology. You may not want to participate in this research because of time constraints. Specific details about the research in which you are invited to participate are contained below. If you do not understand something in this form, please ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If, at any time, you have questions about your participation in this research, do not hesitate to contact the researcher(s) named above or the NC State IRB office. The IRB office’s contact information is listed in the What if you have questions about your rights as a research participant? section of this form.

What is the purpose of this study? The purpose of the study is to gain a better understanding of the impact of body shape in the evaluation of fit using 3D Virtual Design software.

Am I eligible to be a participant in this study? There will be approximately 50 participants in this study. In order to be a participant in this study, you must agree to be in the study and have an interest in providing your evaluation of 3D garments. You cannot participate in this study if you do not want to be in the study or have no interaction with apparel products.

What will happen if you take part in the study? If you agree to participate in this study, you will be asked to do all of the following: 1. to respond to questions that will help researchers understand your satisfaction with the fit of clothing. The total amount of time that you will be participating in this study is approximately 6 minutes.

Risks and benefits There are minimal risks associated with participation in this research. There are no direct benefits to your participation in the research. The indirect benefits are that you will have an opportunity to share your opinions regarding virtual garment fit.

Right to withdraw your participation You can stop participating in this study at any time for any reason. In order to stop your participation, please just close out of the browser window. If you choose to withdraw your consent and to stop participating in this research, nothing at all will be recorded about your interaction. Confidentiality, personal privacy, and data management Trust is the foundation of the participant/researcher relationship. Much of that principle of trust is tied to keeping your information private and in the manner that we have described to you in this form. The information that you share with us will be held in confidence to the fullest extent allowed by law. Protecting your privacy as related to this research is of utmost importance to us. How we manage, protect, and share your data are the principal ways that we protect your personal
privacy. Data generated about you in this study will be anonymous. Anonymous data means that at no time can we, or anyone else link your real identity to the information collected during this research. This means that we cannot identify you at all, even when the data is combined with other information. We will also not seek to identify you using any techniques or technology. Compensation For your participation in this study, you will not receive anything for participating. If you withdraw from the study prior to its completion, nothing will happen. What if you have questions about this study? If you have questions at any time about the study or the procedures, you may contact the researcher, Peyton Hartis, at phartis@ncsu.edu. You may also contact Dr. Cynthia Istook at cistook@ncsu.edu. What if you have questions about your rights as a research participant? If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB (Institutional Review Board) Office. An IRB office helps participants if they have any issues regarding research activities. You can contact the NC State IRB Office via email at irb-director@ncsu.edu or via phone at (919) 515-8754.

Consent To Participate
By continuing on and responding to the survey questions, I am affirming that I have read and understand the above information. All of the questions that I had about this research have been answered. I have chosen to participate in this study with the understanding that I may stop participating at any time without penalty or loss of benefits to which I am otherwise entitled. I am aware that I may revoke my consent at any time.

Consent
I consent to participate in this research:

- Yes (1)
- No (2)

Q1 What is your current job title?
- Product Design (1)
- Technical/Pattern Design (2)
- Product Development (3)
- Merchant/Buyer (4)
- Marketing (5)
- Other (6) ________________________________________________

Q2 What product category do you work with or have you worked with previously? Please select all that apply.
- Children's wear (1)
- Men's bottoms/pants (2)
- Men's tops/outerwear (3)
- Women's bottoms/pants (4)
- Women's tops/outerwear (5)
- Innerwear/undergarments (6)
- Fashion and apparel accessories (7)
- Other (8) ________________________________

Q3 How many years of work experience do you have within the fashion and textile industry?
Q4 In what areas do you currently work or have you worked previously? Please select all that apply.

☐ Product Development (1)
☐ Product/CAD Design (2)
☐ Technical Pattern Making (3)
☐ Sourcing/Logistics (4)
☐ Engineering/Textile Technology (5)
☐ Merchandising/Buying (6)
☐ Marketing (7)
☐ Other (8) ________________________________________________

Q5 Please select your highest education level:

☐ Some high school, no diploma (1)
☐ High school graduate, diploma, or equivalent (GED) (2)
☐ Some college credit, no degree (3)
☐ Trade/technical/vocational training (4)
Associate degree  (5)
Bachelor's degree  (6)
Master's degree  (7)
Professional degree  (8)
Doctorate degree  (9)

Q6 Based on what you know about 3D Virtual Design/Fit software, would you be interested in using 3D virtual design software to visualize garments?

Yes, this would be helpful for design and merchandising/buying.  (1)
Yes, but only for design to help visualize the garment and fit.  (2)
Yes, but only for merchandising/buying to see the potential final product.  (3)
No, this visualization tool would not be helpful  (4)

Q7 Do you currently use or have you used 3D virtual design or visualization tools in your position(s)?

Yes, I use it frequently  (1)
Yes, but only use it sometimes  (2)
Yes, I have used them in previous positions  (3)
No, but my company is transitioning to 3D software  (4)
No, I do not use these programs  (5)

Q8 Which 3D pattern making visualization tool do you use or have you previously used? (Select all that apply.)

☐ CLO 3D  (1)
☐ Optitex  (2)
☐ Browzwear  (3)
Lectra 3D (4)
Gerber 3D (5)
Vidya (6)
Other (7) ________________________________________________

Q9 If you use/have used 3D pattern making visualization software please rate your level of satisfaction from strongly agree to strongly disagree.

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree (1)</th>
<th>Agree (2)</th>
<th>Neutral (3)</th>
<th>Disagree (4)</th>
<th>Strongly Disagree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helps with prototyping (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduces time in the design process (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adds time to the design process (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D garment representative of the final garment (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reflects fit accurately (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following images reflect the fit of a pair of pants on differently shaped bodies using different body avatars. Please provide your assessment of "fit" for each image.

Q10 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.
<table>
<thead>
<tr>
<th></th>
<th>1 (Worst) (1)</th>
<th>2 (2)</th>
<th>3 (3)</th>
<th>4 (4)</th>
<th>5 (Best) (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (1)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.1 (1)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.2 (1)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Q11 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.

Q12 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.

Q13 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.
Q14 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.

Q15 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.

Q16 On a scale of 1 to 5, with 1 being worst and 5 being best fit, please rate the fit of the pants in the image above.
<table>
<thead>
<tr>
<th></th>
<th>1 (Worst) (1)</th>
<th>2 (2)</th>
<th>3 (3)</th>
<th>4 (4)</th>
<th>5 (Best) (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.2 (1)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Q17 Please respond to the following questions based on the images you have just reviewed and your current knowledge of 3D Virtual software technologies.
<table>
<thead>
<tr>
<th></th>
<th>1, least (1)</th>
<th>2 (2)</th>
<th>3 (3)</th>
<th>4 (4)</th>
<th>5, Most (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How interested would you be in using 3D technology for the design and development process for garments? (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How likely would you be to use 3D apparel visualization tools as a substitute for prototyping of garments? (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How does the shape of the avatar influence your rating of garment fit? (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How likely would you be willing to use a 3D avatar generated by the software program? (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How likely would you be willing to use a 3D avatar generated from a body scan? (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The images below represent the fit of pants using different 3D avatars of a specifically shaped body.
Q18 Please select the pant that you believe has the better fit.

A (1)  B (2)
Q19 Please select the pant that you believe has the better fit.

A  (1)  

B  (2)
Q20 Please select the pant that you believe has the better fit.

A (1) B (2)
Q21 Please select the pant that you believe has the better fit.

A  (1)  

B  (2)  

Thanks so much for participating in our survey!

If you have interest in the final survey results, please email the researcher separately (plhartis@ncsu.edu) to let her know and she will share the findings with you when the research is complete.