

ABSTRACT

ABSHER, KATHERINE ALEXANDRA. Exploring the Use of 3D Apparel Visualization to Fit Garments for People with Disabilities. (Under the direction of Dr. Katherine Annett-Hitchcock and Dr. Anne Porterfield).

People with disabilities on a variety of spectrums may face apparel-related challenges on a daily basis. Despite the large number of people who have some kind of disability, apparel products for this population are limited and may not meet the social and aesthetic needs of the consumer. Advances in technology are poised to create systemic changes in product development, design and marketing within the apparel industry. Among these are body scanning and three-dimensional apparel visualization software, which enable a product developer to virtually sew, view and alter a digital pattern on an avatar. These capabilities are becoming industry standard, but little is known of the potential benefits these technologies may offer to people with disabilities. This qualitative study explores the potential for incorporating 3D apparel visualization software into an industry process for fitting patterns for people with body asymmetry, a sub-group of people with disabilities. The study identifies a three-step framework for this process, creating an observational data set, and then analyzes the process for strengths and areas of improvement. Participants with body asymmetry were recruited to the study through local advocacy groups, interviewed and body scanned to generate custom avatars. The researcher used these avatars to conduct virtual fittings of shirt and trouser patterns for each participant, then made the virtual garments into physical samples. The participants tried on these physical garments, were shown their avatar with and without the virtual garments. The participants were interviewed on their response to the avatars, 3D apparel visualization software and their opinion of the fit of the virtual and physical garment samples. Findings from the framework development revealed the process to be a viable way for generating custom garments for people with body

asymmetry. Additional virtual and physical sampling may be needed to successfully fit garments for this population. Participant response to the technology showed discomfort with viewing custom avatars, a positive impression of the 3D apparel visualization software and interest in using virtual try-on in online shopping environments. The main conclusion from this research was the framework which resulted from the process development, and recommended adjustments to that process. This framework could provide benefit to apparel product developers, as well as those involved in the implementation of 3D apparel visualization software into apparel product development processes. Additional benefit may apply to those interested in virtual garment try-on, product development for people with disabilities, mass customization, made-to-order garments and customer co-creation.

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Exploring the Use of 3D Apparel Visualization Software for Fitting Garments for People With Disabilities.

by
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BIOGRAPHY

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CHAPTER 1

Introduction

Background

The World Health Organization estimates that 15% of the world's population lives with some kind of disability (World Report on Disability, 2018). Disability is a complex condition which may take many different forms but essentially reflects disparities between individual ability, environmental demands and societal expectations. The 1991 Institute of Medicine *Disability in America* report described disability as “a gap between a person's capacities and the demands of relevant, socially defined roles and tasks in a particular physical and social environment” (p. 81). Defined as such, disability becomes the result of environmental and social barriers rather than an inherent attribute of an individual (Rosenblad-Wallin, 1985; Curteza et al, 2014; Langtree, 2014). This view of disability has been called the social adapted model of disability, which states that environments and social attitudes inhibit people whose capabilities differ from accepted norms more than any physical impairments they may have (Langtree, 2014). The social adapted model of disability is important for the social inclusion of people with disabilities because it shifts the focus for improvement away from individual ability and onto inaccessible environments and unusable products. Interest in design strategies for accessibility and inclusivity have grown from this view of disability, generating scholarship in methodologies for product development and various frameworks for the product development process (Koberg & Bagnall, 1974; Rosenblad-Wallin, 1985; Lamb & Kallal, 1992, LaBat & Sokolowski, 1999). Designing products and environments to be more inclusive of people with varying abilities provides a means of removing environmental barriers and decreasing their impact on people's lives.

Need for the Study

Research suggests that people with disabilities may face challenges in interacting with their environment on a daily basis (Harter, 1987; Lamb, 2001; Reich & Shannon, 1980; Thorén, 1996; Carvalho et al, 2009). One element of daily life shown in research to present difficulties for people with disabilities is apparel (Wingate et al, 1986; Thorén, 1996; Kabel et al; 2017). These difficulties arise in essence because of the lack of apparel products designed to accommodate diverse bodily shapes and abilities. People with disabilities often struggle to find apparel products that meet their functional, expressive and aesthetic needs (Thorén, 1996). There are few apparel products currently available which are designed specifically for people with disabilities (Wingate et al, 1986; Thorén, 1996; Kabel et al; 2017). In terms of functional needs, many people with disabilities report difficulties with apparel comfort, donning and doffing apparel, and apparel causing restrictions in their mobility (Kabel et al, 2017). Having such limited options means that people with disabilities must often choose between functional and aesthetic considerations, or that they cannot participate in important social activities (Burns, 1996; Kabel et al; 2017). Combined with the everyday difficulties they may face, missing out on social events may increase feelings of isolation or exclusion, which can negatively impact a person's life. Clothing not only serves functional necessities; it has evolved into a staple of our social and psychological constructs. Research has linked clothing with establishing identity, maintaining personal image, communicating social cues and signaling social position (Solomon & Schopler, 1982; Kaiser, 1990; Roach-Higgins & Eicher, 1992). Clothing influences the way individuals perceive themselves and each other, which has an impact on the way people value themselves and treat each other in society (Christman & Branson, 1990; Nisbett & Johnson, 1992; Liskey-Fitzwater, 1993; McNeill, 2018). Research has shown that many people with disabilities

experience embarrassment, humiliation or exclusion because of their clothing (Kabel et al; 2017). Lack of appropriate apparel not only creates physical barriers for people with disabilities, but also becomes social barrier, inhibiting self-expression and undermining social position. Given the importance of clothing from both functional and social perspectives, improved apparel products could be considered a significant way of improving the lives of people with disabilities.

Frameworks for developing apparel products to accommodate diverse consumer needs have been established in research (Rosenblad-Wallin, 1985; Lamb & Kallal, 1992; LaBat & Sokolowski, 1999). These frameworks place the consumer at the center of the design process, positioning their needs as essential elements of product development. In any apparel development process, the needs of the producer and the needs of the consumer form two sets of constraints which must be considered for successful product design (Carroll & Kincade, 2007). Apparel producer and consumer needs can sometimes be in opposition; for example, apparel producers need to create products that fit a wide range of consumers, while individual consumers need products that suit their unique body shape. One element of apparel that challenges both producers and consumers is the fit, or the garment's ability to be the right shape and size (The Oxford Dictionary, 2002). Fitting garments is an iterative process in the apparel industry and presents ongoing difficulties for apparel product developers. Multiple samples of a garment are typically made and assessed before a garment is approved for manufacture, which may be costly and time intensive. Many consumers, including people with disabilities, report dissatisfaction with the fit of ready-to-wear clothing (Loker et al, 2004; Bye et al, 2006; Grogan et al, 2004; Alexander et al, 2005). This is partly because sizing systems do not cater well to individual preference and need, and partly because standard apparel industry operations do not cater well to individualized product

development. However, advances in technology are poised to make major changes in the apparel industry (McDowell & Gaffney; 2019; Shalev, 2019; Shamir; 2018; Mageean & Hanson, 2019; CB Insights, 2020). Among these technologies are body scanning and three-dimensional apparel visualization software. Body scanning is a general term for the technology used to capture images of the three-dimensional surface of the body and render it into a digital environment (Gill, 2011). Gill (2011) cites body scanning among the greatest recent contribution to the sizing and fitting of apparel because it affords a depth of data which allows a better understanding of the body's proportions and relationship to clothing. Recent developments in three-dimensional (3D) simulation software have produced programs designed to enable virtual simulation of apparel which allow the user to visualize, manipulate and evaluate apparel patterns within a virtual environment. As it provides a quick way to view and adjust garment shapes and features, 3D apparel visualization has the potential to reduce sampling in the apparel product development process and improve communication between apparel producers and consumers. Body scanning and 3D apparel visualization technology are predicted to impact the way apparel products are produced and marketed (McGregor, 2016; Mageean & Hanson, 2019). Numerous potential benefits are driving the industry toward the adoption of these tools, including improved sizing systems, improved garment fit, reduced time to market and reduced number of samples (Ashdown et al, 2006; Gill, 2011; Gill & Parker, 2016). Additional applications of this technology may involve customized garment creation and consumer co-design processes, making products more tailored to the individual (Alaimo, 2018; Pardes, 2019; Shamir, 2018; Dou, 2020). People with disabilities tend to be an underserved market in the apparel industry, and it is thought that body scanning and 3D apparel visualization technology could both increase and improve product development for this population (Loker et al, 2005; Rudolf et al, 2017).

Currently, apparel companies are just beginning to find ways of using body scanning and 3D apparel visualization (McGregor, 2016; Mageean & Hanson, 2019). Further study is needed to successfully incorporate these technologies into industry practices for creating or customizing apparel products for people with disabilities.

Purpose of the Study

This research explores the potential of incorporating 3D apparel visualization software into a computer-aided process for fitting garments for people with disabilities. A preliminary framework was developed, which used body scanning to develop custom avatars for participants with disabilities, pattern-design software to derive digital patterns, and 3D apparel visualization to virtually fit those patterns on the avatars. The virtual patterns were then made into physical garments using industry-standard equipment and tried on by the participants. Participants were asked to give their opinion of the virtual and physical garment fit. This research also gathered some initial data on how people with disabilities respond to custom avatars and 3D apparel visualization software. This study is intended to inform the incorporation of 3D apparel simulation into an industry process for customizing garments for people with disabilities. It is expected that this workflow will provide benefit in apparel development research and to apparel product development professionals. There may be additional benefits in the areas of consumer behavior, mass customization and made-to-measure garment creation.

CHAPTER 2

Literature Review

Overview

The literature review is divided into three main sections: disability and the development of apparel products, apparel and disability, and technology in the apparel industry. The first section will present a model for understanding disability and discuss research into the process of developing apparel products. The second section establishes the case for developing apparel for people with disabilities by presenting the social significance of apparel, the apparel-related challenges people with disabilities face and describing how apparel can be used as a rehabilitation tool. The third section discusses research into body scanning and three-dimensional apparel visualization from apparel producer and consumer perspectives.

Disability and the Development of Apparel Products

The social adapted model of disability

The World Health Organization states that approximately 15% of the world's population lives with some form of disability (World Report on Disability, 2018). Disability scholarship offers varying definitions for disability and models for categorizing the types of disability, which include physical, emotional, sensory and developmental (Langtree, 2014). Disability is an umbrella term for impairments (problems in bodily structures or functions), activity limitations (problems in executing tasks/functions), and participation restrictions (problems with involvement in life situations) faced by individuals in society (Curteza et al, 2014). Thus, disability is a complex issue reflecting interactions between features of a person's body and features of the society in which they live (Rosenblad-Wallin, 1985; Curteza et al, 2014;

Langtree, 2014). The Social Adapted Model of Disability states that the society and environment surrounding a person can be more limiting than any physical impairments that person may have (Langtree, 2014). The core of this model is the idea of disability as a social construct rather than an individual problem (Lamb, 2001). Proponents of this view argue that disability is the result of exclusion from society due to inaccessible environments and unusable products, not the result of inherent personal impairment (Lamb, 2001; Carvalho et al, 2009; Curteza et al, 2014; Langtree, 2014). According to the Langtree (2014), the average person spends 40% of their life suffering from interaction problems with their environment; it therefore stands to reason that many people would benefit from decreased difficulties in these interactions.

Apparel was called ‘the portable environment’ by Watkins (1984), because of its close relationship with the human body and the impact it has on individual comfort and safety. Watkins (1984) suggests that clothing creates its own environment for the wearer within their larger environment. One way to alleviate difficulties in interactions with the environment is to improve the design of products and environments to make them inherently more usable and accessible to people with a wider range of abilities (Center for Inclusive Design and Environmental Access, 2018). In terms of apparel products, researchers have suggested design processes for apparel which are more inclusive of people with varying abilities (Lamb, 2001; Lamb & Kallal, 1992; Carroll & Kincade, 2007). These researchers frame consumer needs as essential elements of the design process, rather than limitations on any particular design. Instead of assuming that people with disabilities have apparel-related challenges because of their physical differences, the clothing itself is considered the issue (Lamb, 2001). If more apparel products were designed to accommodate differences in need or ability, fewer people would face apparel-related difficulties.

The apparel design process as creative problem-solving

The development of apparel products can be viewed as a creative problem-solving process (Koberg & Bagnall, 1974). As with any creative process, there are many different approaches for developing apparel products. Research has generated a variety of frameworks, methodologies and processes which provide structure to the apparel development process (Watkins, 1988). Adherence to a structured design process, or framework, may benefit apparel producers as design problems become more complex (LaBat & Sokolowski, 1999). Several researchers have based apparel development frameworks on the work of Koberg and Bagnall (1974), who developed an organizational scheme for creative problem-solving processes. Koberg and Bagnall identified seven sequential steps occurring in creative problem-solving including acceptance of the situation, analysis of the problem, definition of the problem, ideation of goals and solutions, selection of solution methods, implementation of solution techniques and evaluation of results, summarized in Figure 1 below (1974).



Figure 1. Summary of Koberg and Bagnall’s organizational scheme of creative problem-solving (1974).

Among the researchers who based their frameworks on Koberg and Bagnall (1974) was DeJonge (1984), who proposed a process for designing functional clothing emphasizing the importance of clearly defined goals for the design problem. Rosenblad-Wallin (1985) also worked from Koberg and Bagnall (1974) to create a method for designing user-oriented apparel products. This nine-step method highlighted the designers need to understand the demands of the user and their environment to generate successful design solutions. Lamb and Kallal’s (1992) approach to

apparel design, drawn from Koberg and Bagnall (1974) and Watkins (1988), did not distinguish between functional apparel design and fashion design. Lamb and Kallal's process is called the Functional Expressive Aesthetic (FEA) Consumer Needs Model. This model places the consumer at the core of the design process and categorizes the consumer's needs into three types of considerations for apparel products: functional, expressive and aesthetic. Lamb and Kallal (1992) paired these considerations a continuum with each of the other traits: functional-expressive, expressive-aesthetic, aesthetic-functional. These continuums aid the design process in determining the relative importance of each trait in a garment. Lamb and Kallal (1992) combined their consumer needs model with a six-step framework for apparel design, including problem identification, preliminary ideas, design refinement, prototype development, evaluation and implementation (Figure 2). The FEA consumer needs model is integrated into the problem identification stage, when user needs are examined, and into the evaluation stage, when prototypes are assessed according to criteria established in the problem identification stage.

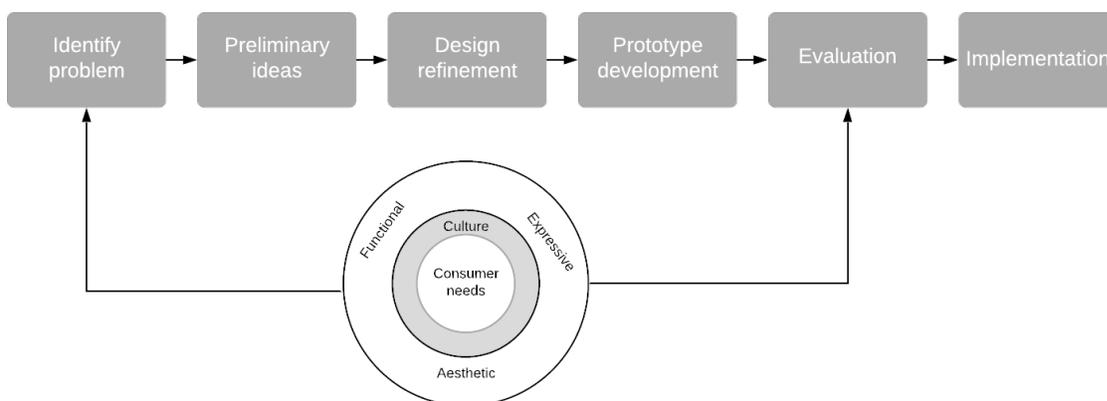


Figure 2. Chart representing Lamb & Kallal's FEA consumer needs model and framework for apparel design, adapted from Lamb & Kallal, 1992.

Considerations for apparel products

LaBat and Solokowski (1999) synthesized the works previously mentioned into a three-step textile product design process: problem definition and research, creative exploration and implementation. This consolidated process is particularly helpful as it begins to define the needs of the consumer and producer within the design framework. The consumer and producer needs create two sets of constraints within any apparel development process (Carroll & Kincade, 2007). These needs and constraints must be considered by the apparel industry in order to create quality products with optimum sales potential. Apparel fit is among the considerations for apparel products for producers and consumers. Fit is considered a crucial element in apparel quality and consumer satisfaction, yet it is difficult to determine what good fit entails as it is dependent on individual perception, style, culture and many other factors (Song & Ashdown, 2010). There are varying opinions on how fit is defined:

‘[Fit is defined as] the ability to be the right shape and size’ – Oxford Dictionary Press, 2010.

‘Fit is defined as a combination of five factors; ease, line, grain, balance and set’ – Erwin and Kinchen, 1969.

‘Clothing that fits well provides an adequate amount of wearing ease (e.g., ease to allow for body movement) and design ease (e.g., ease developed by the designer to create a desired visual effect, silhouette, and style), and follows the silhouette of the body with no undesirable wrinkles’ – Song and Ashdown, 2010.

Fit is an important element in all the frameworks for apparel product development. Individual perception of fit impacts the functional and aesthetic needs of the consumer, which are examined in the problem identification stage of Lamb and Kallal’s (1992) model and in the problem

definition and research stage of LaBat and Sokolowski's (1999) process. Achieving a good fit is also an integral part of the design process for apparel producers. Fit is addressed during the design refinement and prototype development stages of the FEA model (Lamb & Kallal, 1992) and the creative exploration stage in LaBat and Sokolowski's (1999) process. Both the consumer and producer assess the garment fit as part of the evaluation stage (Lamb & Kallal, 1992), which falls into creative exploration in LaBat and Sokolowski's (1999) framework. Thus, fit affects the apparel design process in three areas: understanding consumer needs, prototype development and evaluation.

Apparel and Disability

The social significance of apparel

Apparel products have both functional and symbolic values to individuals and society (Rosenblad-Wallin, 1985; Lamb & Kallal, 1992). Among the symbolic values of apparel is the impression the wearer makes on others through their outward appearance (Rosenblad-Wallin, 1985). Research has established that apparel is integral to appearance and the way individuals present themselves in society (Solomon and Schopler, 1982; Roach-Higgins and Eicher, 1992; McNeill, 2018). Individuals use apparel to create a personal image and communicate a composite of their identity to others (Solomon & Schopler, 1982, Roach-Higgins & Eicher, 1992). Solomon and Schopler (1982) found that apparel can significantly alter appearance, and has major influence on the way individuals are perceived by others and thus has wide social significance. These findings are supported by Roach-Higgins and Eicher (1992), who contend that apparel is central to individual development of identity and communication of identity to others. Apparel also offers symbolic value by communicating messages about the self, such as

group-membership and social position, and providing nonverbal indicators of personal characteristics, such as confidence and competence (Roach-Higgins & Eicher, 1992; McNeill, 2018).

Research suggests that the symbolic value of apparel may be especially significant for people with disabilities and the way they are perceived in society (Thorén, 1994; Nesbitt & Johnson, 1992; Christman & Branson, 1990). A study by Christman and Branson (1990) (N=180) investigated the effects of clothing and disability on perceptions of social and mental competence female job applicants. The study used three levels of dress (most appropriate, moderately appropriate, inappropriate) and three physical conditions (able-bodied applicant, applicant on crutches, applicant in a wheelchair) to determine how characteristics such as personality, competence and professionalism were differentiated by potential employers. Findings showed that applicants with disabilities were rated higher on personality and professionalism when they were moderately or most appropriately dressed; applicants with disabilities were rated significantly lower on competence when they were inappropriately dressed (Christman & Branson, 1990). Nesbitt and Johnson's (1992) (N=183) research examined the effect of clothing 'fashionability' and gender on perceiver impressions of the mental and social competency of people with disabilities. Results indicated that wearing 'unfashionable' clothing negatively influenced perceptions of the mental and social competence of female participants with disabilities. These studies show that personality traits can be differentiated through clothing, that more favorable characteristics may be assumed on the basis of clothing, and that wearing inappropriate or unfashionable clothing adversely impacts perceptions of people with disabilities (Christman & Branson, 1990; Nesbitt & Johnson, 1992).

There is also evidence to support the idea that appearance is greatly important to people with disabilities. Research has found that when an individual has a physical disability, they tend to have a more negative self-concept (Harter, 1987). Teenage girls with scoliosis (N=70) showed significantly lower self-concept than their able-bodied peers, rating themselves lower on social acceptance, athletic competence, physical appearance, romantic appeal and self-worth (Liskey-Fitwater et al, 1993). Liskey-Fitwater et al (1993) also found the relationship between appearance and awareness of clothing was stronger for teenage girls with scoliosis than without. The indication is that appearance is a key factor in self-concept, and that people with disabilities need clothing which supports their desired self-image to develop a positive self-concept.

Apparel-related challenges for people with disabilities

People with disabilities may have different apparel needs according to their spectrum of disability (Reich & Shannon, 1980; Thorén, 1996; Carvalho et al, 2009). Differences in body shape and posture; range of motion, dexterity and mobility may all factor into the apparel-related needs of people with disabilities (Reich & Shannon, 1980; Thorén, 1996). Research shows that people with disabilities often have difficulty finding apparel that meets their functional, expressive and aesthetic needs (Reich & Shannon, 1980; Thorén, 1996). Thorén suggests this is because the modern apparel industry is not adapted for people with different bodily dimensions and abilities (1996). People with disabilities may not fit into current industry sizing systems, may have difficulty accessing retail options, and may be in need of specialized adaptations of their clothing (Thorén, 1996). There are few apparel companies that produce products for people with disabilities, and the options they afford may not meet the expressive or aesthetic needs of people with disabilities (Carvalho et al, 2009; Reich & Shannon, 1980; Thorén, 1996; Kabel et al., 2017;

McNeill, 2018). Lamb (2001) notes that functional apparel products designed specifically for people with disabilities are often presented in medical supply catalogs, which may contribute to the stigmatization of functional clothing and the social isolation of people with disabilities. Freeman et al (1985) determined that people with disabilities often feel ambivalent about functional clothing, and may perceive it as compromising to their individuality and self-presentation. Research has shown that internal stigmatization may occur in conjunction with the use of functional clothing (Freeman et al, 1985; Kaiser et al, 1985; Wingate et al, 1986). A study by Wingate et al (1986) (N=322) examined people with disabilities' perceptions of functional clothing. Their findings indicated the increased potential for internal stigmatization as the functional features of the garments became more noticeable.

The lack of clothing options can diminish the quality of life and participation in society for people with disabilities (Kabel et al., 2017; Carvalho et al, 2009). Kabel et al.'s (2017) survey of people with physical disabilities (N=113) found over sixty percent of respondents reported that issues with apparel made it difficult to carry out every-day activities, and that apparel had made them feel embarrassed or humiliated. Sixty percent also reported that they had missed important life events or declined to participate in social activities like school dances, weddings, funerals, graduation ceremonies or sporting events due to clothing problems. Missing important life events can have negative impacts on relationships and contribute to feelings of depression, isolation or negative self-concept that people with disabilities may already feel (Kabel et al., 2017).

However, studies have also shown that clothing can be a tool for building self-esteem and improving life skills (Freeman et al, 1985; Kaiser et al, 1985; Liskey-Fitzwater et al, 1993).

Liskey-Fitzwater et al (1993) points out that “actual appearance is not the central issue; it is the individual’s perceptions of his or her appearance and of how others view that appearance that are important.” Clothing has potential to improve an individual’s perception of their own appearance and empower them to influence the perceptions of others (Freeman et al, 1985; Kaiser et al, 1985; Thorén, 1996). Interview data (N=36) suggests that people with disabilities emphasize the desire for self-help features and prefer to dress themselves when possible, supporting the idea of clothing as an instrument of self-efficacy (Freeman et al, 1985). However, research indicates that people with disabilities often try to de-emphasize their differences and prefer apparel products they consider normative, as opposed to distinguishing themselves through apparel choice (Freeman et al, 1985; Kaiser et al, 1985; Thorén, 1996). People with disabilities often express the desire to look as ‘normal’ as possible, that they do not want to appear ill or impaired, and that functional clothing is a visual cue that they are different (Freeman et al, 1985; Kaiser et al, 1985; Thorén, 1996). Freeman et al (1985) identified several strategies for alleviating the stigmatization of functional apparel, including making personal adaptations to normative apparel and incorporating functional features into all apparel design. These strategies speak to the principles of inclusive design, which seeks to not to change but to improve the design of products by making them ‘more safe, usable and appealing to people with a wide range of abilities’ (Center for Inclusive Design and Environmental Access, 2018).

Research has shown that designing apparel to minimize difficulties caused by physical limitations can be a successful strategy for product development (Carroll & Kincade, 2007). Carroll and Kincade’s study (2007) into inclusive apparel design for working women with physical disabilities followed a co-design process between the researchers and participants (n=9)

to develop a jacket prototype with features found appealing by the participants. This prototype was then wear-tested by the participants with disabilities and another sample of working women without physical disabilities (n=6). The prototype was generally rated highly by both groups; a majority of participants found the garment to be as they had envisioned or better during the wear-test, indicating that products designed to meet the needs of people with disabilities can have appeal beyond the group they were designed for. Unfortunately, apparel-related research for people with disabilities has not led to greatly increased product development for that population. Carroll and Kincade's (2007) study revealed some of the reasons behind this. The jacket prototype developed in the study was evaluated by a group of professionals from the apparel industry (N=6). Although the prototype was found to be easy to engineer and produce, manufacturers had concerns that the product was incompatible with their current operating and marketing procedures, and perceived the product as lacking mass-market potential (Carroll & Kincade, 2007). These findings show that designing and manufacturing garments for people with disabilities is only part of the challenge, and that efforts toward increasing product availability for people with disabilities should incorporate feasible ways marketing these products.

Technology in the Apparel Industry

Overview

This section will introduce the two types of technology relevant to this research: body scanning and three-dimensional apparel visualization software. Research involving these technologies and apparel product development will be presented, industry use of these technologies will be discussed and the response to these technologies from consumer and producer perspectives will be examined.

Introduction to Body Scanning

Body scanning is a general term for technology used to capture an image of the three-dimensional surface of the body (Gill, 2011). The initial data gathered by body scanners is a set of several million xyz coordinates in a disorganized dispersion, which is often called a point cloud (Gill, 2011). Most body scan suppliers (e.g. [TC]2, Size Stream LLC, Human Solutions GmbH, Styku) also provide a software package to facilitate the extraction of body measurement data and the processing of point cloud data into three-dimensional digital representations of the human body, or avatars (Gill, 2011). Body scanning is able to provide a huge amount of data about the human body, which has potential to enhance product development processes. While body scanning has not yet provided a panacea for issues related to apparel fit, sizing or customization, it has generated some innovative approaches to apparel development and new areas of study (Gill, 2011).

Apparel-related research and industry applications of body scanning

Research related to body scanning and apparel product development has been conducted on several wide topics. Studies have shown that body scan data may enable apparel producers to improve sizing and grading systems, and to tailor current sizing systems to their target market (Bougourd, 2005; Loker et al, 2005, Ibanez et al, 2012). Other studies have explored the potential of body scanning for analyzing body shape and measurement data of whole populations. Among the researched applications for this data are the creation of body shape and measurement databases (Bougourd, 2005); quantification of anthropometric differences among populations (Schranz et al, 2012); the classification of populations by body shape (Lee et al, 2007; Su et al, 2015; Wilson & Istook, 2016; Wu et al, 2018); the development of customized apparel patterns based on classification of body features (Su et al, 2015), and the creation of

parametric and customized avatars (Berdic et al, 2017; Brownridge & Twigg, 2014.) Some researchers suggest that integration of body-scanning technology into the apparel industry offers opportunities for the individual to again become central to apparel product development (Ashdown et al, 2007; Gill, 2011; Tsakalidou, 2017). This could benefit many types of consumers, but some researchers are particularly interested in the benefits for people with disabilities. Previous studies using manual methods for anthropometry, or measuring the human body, indicate that body scanning could be an ideal way of collecting body measurements from individuals with disabilities because it is fast, efficient, non-contact and relatively accurate (Hernandez, 2000; Tsakalidou, 2017). Tsakalidou suggests using body scanning data to develop specialized sizing systems for sub-groups of the population with disabilities, such as people with scoliosis (2017).

Global apparel consulting firms that develop sizing tools and gather market data, such as Alvanon, are collecting and analyzing body scan data to help brands develop targeted sizing systems and improve fit across sizes (Alvanon's Data Gathering & Analytics Solutions, 2020). A study by De Raeve et al (2017) (N=529) yielded four new sizing tables for average-sized adults. Improved sizing systems have potential to build consumer loyalty to brands and increase sales (Lewis & Loker, 2017). Research also links body scanning to enabling mass customization of apparel and footwear (Beringer, 2019). Some startup companies, such as RedThread, Isabella Wren and ProperCloth, are interested in these applications for creating custom clothing using mobile body scanning technology and tailoring algorithms, which automate the process of adjusting patterns based on measurements taken with the body scan (Alaimo, 2018; Pardes, 2019). This approach eliminates sizes altogether, aiming to provide a more precise fit (Alaimo,

2018; Pardes, 2019). Lewis and Loker's (2017) research identified several suggestions for the integration of body scanning into apparel store environments, particularly for size suggestion for product categories that are difficult to fit, such as swimwear. Their research indicated that apparel retail employees (N=71) see body scanning as a way to interact more with the consumer in-store, to better understand consumer needs, and to allow them to make suggestions for products the consumer may not have considered (Lewis & Loker, 2017). Apparel companies may begin to capitalize on these opportunities in the next few years (Lewis & Loker, 2017). Beringer also (2019) points out that improved sizing systems and online size suggestion tools made possible by body scan data could help reduce apparel product returns for the retail industry.

Body Scanning for Custom Avatar Development.

The apparel industry has established practices of using physical models representing industry sizes called dress forms for fitting apparel products in real life (Gill, 2011). When using 3D software for designing and fitting apparel products in a virtual environment, digital models of the body are also needed. These models are generally referred to as avatars, which are three-dimensional digital models of the human body (Gill, 2011). Customized avatars can be made in several ways, such as building them in 3D modeling software, adjusting the parameters of pre-made models, and reverse-engineering point cloud data from a body scanner (Liu et al, 2017). Building avatars with digital modeling software may be impractical for product development purposes because it is time-intensive and requires a high skill level in 3D modeling software (Liu et al, 2017). The apparel industry mainly uses pre-made parametric models representing industry sizes for product development using 3D software (Gill, 2011). As most apparel companies sell a range of sizes as opposed to customized apparel products tailored to individuals, using parametric avatars makes sense. For the purposes of creating customized apparel products,

parametric avatars are less helpful, as they do not reflect individual variation in body shape, dimension, structure or form. Parametric avatars are adjustable to a certain extent, but research has found that accurate modification of parametric avatars isn't always possible because of programmed interrelations of certain body measurements, which cause one measurement to impact the value of another (Porterfield & Lamar, 2017). Research also found that the avatar development method impacts virtual garment fit, and that for an individual consumer, a custom avatar made from body scan data provided a more accurate fit than a parametric avatar (Lim & Istook, 2011). It is logical that a custom avatar would offer an individual consumer a more accurate virtual fit than a stock avatar; and has implications for using body scanning to create custom avatars for people with disabilities. As it currently impossible to modify parametric avatars to accurately reflect individual body measurements, differences in posture, body asymmetry or limb differences, using body scan data remains the best option for this purpose.

However, there are some technical challenges in body-scanning people with disabilities, which has likely contributed to the lack of scholarly research in this area. Software packages for rendering point cloud data into avatars and extracting measurement data tend to be based on a set of expectations about the body, assuming a standing posture, two arms and two legs (Gill, 2011). The software may be unable to extract a set of measurements for bodies that don't conform to these standards. Without the set of measurements, the software cannot generate an avatar that could be exported into other 3D apparel software. This creates a barrier for people who have disabilities which limit their ability to stand upright, balance and maintain stillness for the duration of the scanning process. Another challenge relates to the automatic avatar editing features used by many body scanning software packages. The raw point cloud data generated by a body scanner often includes 'noise' data, or extra points detected by the scanner which are not

reflective of the individual's body. It may also have 'holes,' where the scanner did not detect enough data, or where areas of the body were occluded. Areas of the body that are less 'visible' to the scanner, such as under the arms and between the legs are especially prone to inaccuracies and may be filled in automatically by the software. The automatic fill-in process tends to overfill the area, and that excess data could cause fitting problems in virtual try-on. Excess and missing data can cause avatars to have discrepancies that need to be edited to create a closed body model with a surface smooth enough to allow virtual try-on (Lim and Istook, 2011; Kim & LaBat, 2012). To facilitate this process, the body scanning software package usually offers an interface wherein the user can 'optimize' the avatar by smoothing the body surface, filling in the holes and making the body symmetrical. However, these 'optimization' functions may not be customizable, meaning that the product developer does not have much control over the avatar editing process. The concern with these automatic features is that they may result in significant changes to the body measurements and shape, rendering the avatar a less effective tool for fitting virtual apparel (Size Stream, 2020). For the purposes of creating customized avatars for people with body asymmetry, features like making the body symmetrical are not helpful. It's important to note that these challenges are relative to the particular body scanner and software package being used. It is hoped that more advances in technology will enable scanners to capture accurate data regardless of individual shape or body position. There are already some scanning systems that offer this capability, but not all scanners being used in the apparel industry are so equipped (3dMD, 2020; Human Solutions, 2020). In the meantime, research and commercial endeavors must take the technical limitations into account when planning to body scan individuals with disabilities.

Introduction to 3D apparel visualization

Three-dimensional apparel visualization software is a general term for computer programs that enable a virtualized pattern to be sewn, draped and altered on an avatar (Gill 2011, Kim & LaBat, 2012; Porterfield, 2014; Porterfield & Lamar, 2017). Additional functions of the software may include the creation of renderings and animations of the garments and the creation of virtual store environments. There are several different 3D apparel visualization software options available, including Lectra Modaris 3D Fit (France), 3D Runway Designer by OptiTex, VStitcher by Browzwear Solutions Pte Ltd, e-fit Simulator by Tuka Tech, and CLO Virtual Fashion (Korea) (CLO Virtual Fashion, 2020; EFI Optitex, 2020; Lectra Fashion PLM 4.0, 2020; Tukatech, 2020; VStitcher 3D Apparel Design Software, 2020). Some programs are so new that there is virtually no scholarly research yet published using them. The apparel industry is rapidly expanding the use of 3D apparel visualization software in their product development and marketing practices, but questions regarding the capabilities and uses of the technology remain (Mageean & Hanson, 2019).

Industry uses of 3D apparel visualization

Apparel companies are rapidly exploring the use of 3D apparel visualization software and how it can assist in apparel design, product development, merchandising and marketing (Mageean, 2019; Mageean & Hanson, 2019; McGregor, 2016). As product development teams face increasing pressure to reduce lead time, respond faster to trends and increase margins, companies are looking for digital solutions to perennial problems in design, development, sample production and planning. International fashion supplier Bonprix is incorporating 3D Vidya by Assyst into their product development process, with the goal of significantly reducing the

number of physical patterns. Though they began with limited product categories including shirts and nightwear, the company plans to extend 3D apparel visualization across their entire range of products, citing faster lead times and fewer resources used (Mageean & Hanson, 2019). Chico's FAS, Inc has also been an early adopter of 3D apparel visualization. Initially, the company's aim was to reduce the number of samples needed to get a style approved, as their fitting process was causing a bottleneck in sampling which reduced their time to market and their profit margins. These applications are focused on product development processes, not consumer visualization or marketing. Chico's reported 3D software's efficacy in digital product creation and expects it to reduce costs and improve margins as they incorporate 3D across their three brands (Mageean, 2019). At Target, bringing Optitex into the workflow has allowed a more iterative, faster design and development process. The company has reduced product development time by approximately two weeks and reduced sampling by sixty-five percent. They also use 3D software extensively for merchandising, visualizing store layouts and line planning (McGregor, 2015). Similar benefits have been reported by Under Armour, who adopted Optitex in 2015 after deciding to redesign its entire Fall 2015 women's collection in 3D, only weeks before sales meetings (McGregor, 2016.) These experiences from major fashion companies show the huge potential of 3D apparel visualization to impact many areas of the apparel industry.

Research in 3D Apparel Visualization

Research indicates that 3D apparel visualization is a helpful tool for assessing the overall design of a garment and can help industry professionals make and communicate decisions about color, print scale and proportion (Lee and Park, 2017; Song & Ashdown, 2015; Porterfield & Lamar, 2017). A number of studies into virtual garment simulation have focused on measuring the validity of 3D apparel visualization software by comparing images of virtual garments with

images of physical garments. A study by Lee and Park (2017) analyzed the differences between virtual and actual samples to assess the software's efficacy as a fit assessment tool. They concluded that when the garment fit is acceptable, the 3D simulation is reasonably accurate, but when the garment fit is poor, the software cannot realistically represent the fitting problems (Lee and Park, 2017). Song and Ashdown's (2015) study on the visual fit assessment of real and virtual pants identified several areas for improvement. They reported that the software shows stress folds resulting from a very tight or loose misfit but can't represent small folds caused by a slight misfit (Song & Ashdown, 2015). The study also showed that virtual pants represented less ease than actual pants, and that virtual fit is affected by body shape (Song & Ashdown, 2015). This means that some consumers will get a better virtual representation of fit than others, indicating that the effectiveness of the software has limitations when body shape deviates from the norm, emphasizing the importance of studying applications of 3D software for people with non-standard body shapes. Porterfield and Lamar's (2017) study supported Song and Ashdown's findings about body shape, reporting that the body shape and posture of an avatar visibly affected the drape and fit of virtual garments. Another study examined the validity of 3D garment simulations by comparing measurements taken from images of real garment samples against images from 3D garment simulations in different fabrics (Wu et al, 2011). They found that simulation images were consistently smaller at the hip level and inferred a bias in the software. Their results indicated that the measurements were most similar at the waist level and least similar at the hip level; consequently, they concluded that the software needs improvement before it can be used confidently in fit evaluations (Wu et al, 2011). Overall, research indicates there are some questions around accuracy of the software and the efficacy of the tools available, as could be expected with such a new technology. Many studies focus on validating virtual fit,

but fewer studies exist which explore the use of 3D apparel visualization software for virtual fitting.

Research using 3D to develop apparel for people with disabilities

There are a handful of studies exploring the use of body scanning and 3D apparel visualization to develop apparel products for people with disabilities. General findings indicate that there is potential for development in this area and 3D apparel visualization provides avenues for new approaches to custom garment creation. A study exploring virtual prototyping for trousers designed for paraplegics concluded that the creation of a virtual prototype was helpful and effective in the product development process (Rudolf et al, 2015). Two studies using this technology focused on people with conditions related to body asymmetry, e.g. scoliosis (Hong et al, 2018; Bruniaux et al, 2016). These studies primarily explored ways of digitizing and automating the process of generating customized patterns for people with diverse body shapes. A recent case study used 3D apparel visualization to develop an automated method for creating customized garments for people with scoliosis (Hong et al, 2018). Their method involved body scanning a participant, assigning 'anatomical landmarks for garment design' on the avatar and triangulating those landmark points to derive a basic block. The result was a close-fitted, customized block bodice from which desired styles could be drafted. The study also included a mathematical assessment of the similarity between real and virtual samples using key fit measurements defined by the researchers. They found that their physical samples were rated 88% - 94% similar to the virtual samples (Hong et al, 2018). Another study compared two methodologies for creating custom garments for women with scoliosis (Bruniaux et al, 2016). The first method involved trying different sized patterns on their subject's custom avatar to determine the best size, and then digitally modifying the basic pattern to fit the individual. The

researchers called their second method ‘3D direct tailoring,’ because it involved digitally tracing outlines of the pattern onto the avatar using salient body landmarks and morphological curves. They derived the pattern by flattening these shapes, adding ease and adding the neck and armhole curves. Their overall conclusion was that both methods resulted in better fitting garments than the original patterns provided (Bruniaux et al, 2016). The researchers noted that it was difficult to assess ease when virtually fitting the patterns using the first method, but that the resulting pattern was closer to industry conventions. Having a pattern that aligns more closely with industry standards may make it easier to scale the process into an industry practice. The ‘3D direct tailoring’ method allowed the researchers to better manage the ease, but it required a lot of manual finesse with the digital tailoring lines (Bruniaux et al, 2016). These studies are some of the only available literature on using 3D apparel visualization for customizing garments for people with disabilities, and because they are exploratory in nature, they raise questions rather than provide solutions. Neither study provided any framework for incorporating 3D apparel visualization into industry processes, leaving opportunities for future research.

Consumer response to body scanning, avatars and 3D apparel visualization.

Research discussed in previous sections focused on the potential benefits of body scanning and 3D apparel visualization for the apparel industry from a product development point of view. However, these technologies also need to be examined from a consumer perspective. While improvements in product development offer benefits to consumers, it is important to consider the psychological impact of these technologies (Kim & LaBat, 2012). Consumer response to body scanning technology and interacting with custom avatars and 3D apparel visualization software therefore warrants investigation, not only to understand consumer perspectives but also to assess the viability of engaging consumers in commercial applications of these technologies. General

findings from research indicate that many customers have a high level of interest in these technologies and would consider using them the future but may express discomfort with seeing their scan output and have concerns about data privacy (Kim & LaBat, 2012; Loker et al, 2004; Grogan et al, 2016; Ridgeway, 2017). Research also shows a tendency for consumers to have a more positive reaction to the technology itself than to the representation of their body the technology affords (Kim & LaBat, 2012; Loker et al, 2004; Grogan et al, 2016; Ridgeway, 2017).

Research has found that some consumers tend to feel uncertainty before being scanned, but generally feel much more comfortable with the process afterwards (Loker et al, 2004; Grogan et al, 2016). A study of female consumers by Loker et al (2004) (N=203) found 98% of their sample willing to be scanned again, after they had completed the scanning process for the first time. A much lower proportion of women felt comfortable with the scan output image of their body. Only 55% of Loker's sample (N=203) (2004) felt comfortable or very comfortable with viewing their scan, and only 38% reported they'd be comfortable showing the scan to friends or family. A more recent study supported these findings and concluded that body scanning is not recommended for promoting body positivity (Grogan et al, 2016). Over half Grogan's sample (N=91) reported some degree of body dissatisfaction at the time of the scan, and 34% reported feeling more negatively about their bodies since the scan. Women with low body satisfaction were most likely to feel shocked, made vulnerable or upset by the scan images. Even women with higher body satisfaction reported increased self-objectification after scanning, though it was positively framed as providing body size information that could be used to choose better-fitting clothes (Grogan et al, 2016). More recently, Ridgeway (2017) (N=101) conducted a study examining men's and women's body-image satisfaction, mood and likelihood to engage in

appearance-management behaviors before and after viewing custom avatars of themselves. The results supported previous findings that body-image satisfaction and mood decreased for both men and women post-avatar viewing, and that both genders reported an increased desire to manage their appearance after viewing their avatar. Ridgeway suggested that these findings were due in part to the novel, unfamiliar perspective on the body provided by the avatar. Viewing oneself from all angles is very rare in real life, so the new knowledge obtained from an avatar results in a greater discrepancy between actual and ideal self-image. As this actual-ideal self-image discrepancy increases, so do dejection-related emotions like body dissatisfaction and dampened mood. (Ridgeway, 2017).

Nevertheless, the research also found many customers consider body scanning and virtual try-on to be a fun and interesting new experience they'd be willing to use for online shopping (Kim & LaBat, 2012). Kim and LaBat's study (N=37) showed half of their participants having a strong positive response toward using the technology in the future. Another common response from the research was that the body scanner provided information the participants couldn't get from other sources, like a mirror (Grogan et al, 2016). Many women were interested to see an 'accurate and objective' view of their body size and shape and found the measurements helpful. At the same time, women tended to distance themselves conceptually from their image file, an unfamiliar yet very personal way of viewing themselves (Loker et al, 2004; Grogan et al, 2016). These results indicate an underlying assumption that body scan images are valid, and somehow more accurate or objective than other means of viewing oneself. While a high level of confidence in the accuracy of the technology is central to increased adoption, this could be problematic if it leads to increased self-objectification. Because prior research has shown that people with disabilities often have difficulty finding appropriate clothing or have challenges with dressing, body

scanning and virtual try-on technology could offer many benefits. However, studies have indicated that people with disabilities may experience lower self-concept than able-bodied people (Liskey-Fitwater et al, 1993; Kabel et al, 2017); it is possible that using this technology could have a more negative impact on them. Currently, there is little information available about the way people with disabilities respond to these technologies. Available studies tend to focus on younger, able-bodied, female consumers so there is a need for research that includes men, people with disabilities and a wider age range. Overall, research into customer response to body scanning and virtual garment simulation indicates the vast potential of consumer involvement in a variety of apparel applications using these technologies. The observed uneasiness with such a new process and technology suggests that research and commercial endeavors should make concerted efforts to familiarize consumers with the technology and the process.

Product developer response to using 3D apparel visualization technology

Relatively little research has been conducted which includes information about product developers' responses to using 3D apparel visualization technology for apparel design and product development. Available studies indicate that product developers tend to feel curious and enthusiastic about virtual garment simulation software, especially about using the software to communicate design ideas (Baytar & Ashdown, 2015; Porterfield, 2014; Porterfield & Lamar, 2017). Baytar and Ashdown's (2015) research provided in-depth analysis of eight design student's responses to being body scanned to create a custom avatar which they used in 3D apparel visualization software program commonly used in industry to design garments for themselves. Findings included generally positive reactions from participants on learning and using the 3D software, participants finding features of the program to be engaging, and

participants expressing the opinion that using the software to co-design apparel may lead consumers to value their garments more (Baytar & Ashdown, 2015). Contrary to the researcher's expectations, participants almost unanimously preferred their avatars' monochromatic surface as opposed to having a more realistic skin texture. Although some participants described their avatars as 'creepy' and 'weird,' participants tended to feel the monochromatic texture was less distracting for product development purposes and generally expressed the opinion that they did not want any more realistic detail of their appearances than the custom avatar already offered (Baytar & Ashdown, 2015). Porterfield's (2014) research developed a framework for incorporating 3D apparel visualization into the costume design and development process. All participants in Porterfield's research felt 3D apparel visualization could contribute to design communication; many also felt that early stage design decisions could be made with virtual prototyping. While participants were divided on using the software for fitting, they generally felt 3D apparel visualization had value in prototyping and communication that could benefit their product development process.

Summary of Literature Review

Disability is a result of exclusion from society due to social and environmental barriers. Removing these barriers through design processes for products and environments is a means for promoting accessibility and inclusivity in society. Consumer-needs centered strategies for developing apparel products have been developed in research. Apparel is an important element of daily life from a functional and social point of view, yet there is a lack of apparel products designed to accommodate diverse body shapes and abilities. Many people with disabilities struggle to find appropriate clothing and face daily challenges with apparel products, impacting

their comfort, safety and inclusion in society. Advances in body-scanning and 3D apparel visualization software have potential to change product development processes in the apparel industry, which could positively impact this population. As of yet, relatively few studies have explored the use of body scanning and 3D apparel visualization in the creation of garments for people with disabilities. People with disabilities have also been underrepresented in research involving body scanning and 3D apparel visualization. Thus, there is little data available on customer response to these technologies for people with disabilities. Research has shown some promising applications of 3D apparel visualization, but it remains very new to the apparel industry and requires further exploration. Little research has been published which explores pattern manipulation with 3D apparel visualization software.

CHAPTER 3

Methodology

Research Design

The literature review presented consumer-centered frameworks for product development, established the need for apparel product development for people with disabilities, presented two technological avenues for exploration in this area, and examined consumer response to these technologies. This research develops a framework for fitting apparel for people with disabilities using body scanning and 3D apparel visualization technology. This research also examines people with disabilities' responses to custom avatars and 3D apparel visualization software. An exploratory, qualitative research process was determined to be the most effective method for several reasons. Qualitative methods often involve the exploration of emerging questions and procedures (Creswell, 2013). A qualitative approach is also used for research into individual meaning, reporting the complexities of a situation and discovering individual preferences, opinions and feelings (Creswell, 2013). This research proposed and analyzed an apparel-product development framework incorporating body scanning, 3D apparel visualization and pattern making software to produce and fit sample garments for a small number of participants with body asymmetry. Body asymmetry was selected as a category of disability because standardized patterns in the apparel industry are primarily developed for one half of the body with the understanding that the other half is within industry-standard tolerance of deviation and therefore does not require separate patternmaking. This presents a challenge for the percentage of the population whose bodies differ more than a standard deviation between left and right side and could explain poor fit in standardized garments for the percentage of the population whose bodies differ more than that standard deviation between right and left sides.

Two research objectives were developed to guide the study:

RO1: Develop a framework for using 3D apparel visualization software to fit patterns on avatars of people with body asymmetry.

RO2: Assess people with body asymmetry's responses to custom avatars and the use of 3D apparel visualization.

The following strategies were employed to fulfill the research objectives:

1. Identify and recruit a small sample of participants with disabilities related to body asymmetry.
2. Gather body scan data and develop an avatar for each participant. Gather demographic information and interview data related to apparel needs, preferences and challenges from each participant.
3. Use 3D apparel visualization software to virtually fit patterns on each avatar.
4. Produce physical samples of these virtual garments.
5. Review and try-on physical samples with each participant and assess participant responses to virtual and physical fit.

Elements from steps two through five above were related to the process of developing the framework described by RO1. The implementation of those steps forms an observational data set and is therefore reported in the findings and discussion section of this paper (Chapter 4). The following paragraphs will provide details on the sample description, recruitment protocol, how data was collected and analyzed in this research.

Sample description & recruitment

Limitations from the technology available to the researcher imposed certain criteria on the participants eligible for recruitment. The body scanner available to the research team was programmed based on an assumed body posture and body shape. Prior research has shown body scanners may have difficulty capturing accurate data when the scanned individual's body did not conform well to these assumptions (Gill, 2011; Lim and Istook, 2011; Kim & LaBat, 2012). To focus the study, the researcher recruited individuals with body asymmetry, including scoliosis, kyphosis, lordosis, partial or full absence of upper limb, or variation in posture. These criteria were intended to ensure the scanner used in research would be able to successfully generate an avatar for eligible participants, given the technology limitations inherent in using the available system for the selected population. Sample selection was based on three main criteria: type of disability, availability, and the ability to travel to the researcher's location. Participants were recruited via an online survey tool (see Appendix B) distributed through email to local advocacy and support groups. This survey was designed to eliminate any candidate who did not meet all the eligibility criteria for the study. The preliminary nature of this study and limitations in the resources available to the researcher made it necessary to limit participants to a small target sample (N=5-10). In this research, n=22 recruitment emails were sent out, returning n=8 respondents to the recruitment survey. However, only three subjects were deemed eligible for the study, once recruitment time had expired (one month), and one of those three was unable to complete the study. The remaining participants are called Subjects A and B for privacy protection.

Data Collection Instruments & Analysis

Three main instruments were used for data collection: a survey, interview protocols and process notes. An online survey tool was used for participant recruitment as described above.

Participants were interviewed twice in this research. The first interview (see Appendix C) was conducted when each participant was body-scanned; this interview was intended to gather demographic information and data on each participant's apparel-related needs, preferences and challenges. The second interview occurred when the participants returned to see their avatars, interact with the 3D software and try on their sample garments. This interview (see Appendix D) assessed participant reactions to their avatars, virtual garments and physical garments. The observational data set formed by the researcher's experiences through the research were collected through process notes. The analysis of those notes became the framework output and assessment. Analysis of interview data followed an 'open' coding method, which aims to identify discrete concepts for comparison and is commonly used in qualitative research (Akinyode & Khan, 2018). The interviews were recorded and transcribed. The interview scripts were coded into nodes, which were sorted into categories. These nodes and categories were not pre-determined but arose from the information provided by the participants in their interviews. Information directly related to the research questions was separated from the additional information provided by the participants. The data relating to the research questions was grouped into four main themes: responses to the avatars, the 3D software, the virtual garment samples and the physical garment samples. The interview data in each theme was then interpreted according to the research questions, specifically in two areas: participant reaction to the avatars and technology and the participant's reactions to the virtual and physical garments.

CHAPTER 4

Findings & Discussion

Overview

Findings from this research will be discussed in two main sections. The first section reports specifics of the framework development and provides detail on the researcher's observations and decision-making along the way. The second section will cover findings pertaining to the participant responses to the technology.

Section 1: Framework Development

The framework developed in this research offers a potential method for using 3D apparel visualization software for fitting garments for a sub-group of people with disabilities. The research process as a whole incorporates elements which address each step in Lamb and Kallal's (1992) FEA Consumer Needs Model (See Figure 2). The first three steps in this model, (identifying the problem, preliminary ideas and design refinement) were addressed in the design of this study, as discussed in Chapter Three. The steps of this framework fit within the prototype development and evaluation stages of Lamb and Kallal's model (1992). The framework itself and findings from its development are expected to aid in future implementation (the final step of the FEA model) of this process in research and industry. Steps of the process were planned based on knowledge of the software programs and the resources available for the study. The initial framework was mapped out as follows:

1. Develop an avatar for each participant using a 3D body scanner.
2. Alter selected patterns using 3D apparel visualization software.
3. Review avatars, virtual garments and physical garments with participants.

Details of Steps 1-3 listed above were developed through observations during the process. These observational data will be reported by a description of each process step, which will have its own organizational chart, followed by discussion of the challenges met in each step.

Step 1: Develop an avatar for each participant using a 3D body scanner

The first step of the framework was to develop an avatar for each participant as an (.obj), a type of file compatible with the 3D apparel visualization software and a basic output of the body scanning program. There were several reasons behind the research team's decision to use customized avatars from body scan data as opposed to adjusting parametric avatars available in the 3D software. Firstly, given this study's focus on disabilities related to body asymmetry, parametric avatars would not represent differences in body shape and dimension. Secondly, prior research showed custom avatars from body scan data provided a more accurate representation of fit for individual customers as compared to parametric avatars (Lim & Istook, 2011). Subjects were provided information about the body scan process in the recruitment survey to provide clarity about the body scanning process, including photos illustrating how the participants would need to stand in the scanner, and what the scan output looked like. Participants were also informed of their options as to what to wear during the scan: either close-fitting, tight clothing such as leggings or their undergarments. Both participants preferred to wear sports bras and athletic leggings during the scan. Previous studies have found that the point cloud data from a body scanner used to generate an (.obj) may have excess or missing data points, which may cause changes to the avatar's shape that are inaccurate to the scan subject's appearance (Lim & Istook, 2011). Excess data may often be found in areas of the body that are most difficult for the body scanner to scan, such as under the arms and between the legs. The appearance of excess

data in these areas is often similar to webbing – the space between the upper legs or between the torso and arm is filled in where it should be empty (see Figure 3 below). These discrepancies may hinder virtual garment try-on and impact the similarity between the subject and the avatar.

To facilitate creation of avatars more suited to virtual try-on, the body scan program included an avatar editing interface with automatic ‘optimization’ features. These features are typically used to smooth the avatar’s surface and make the avatar bilaterally symmetrical, however, these features are not applicable to participants with disabilities related to body asymmetry. To preserve as much detail as possible, a digital artist was enlisted to manually edit the (.obj) files from the body scanner using ZBrush, a 3D modeling program. This editing process was intended to remove enough ‘webbing’ to allow the virtual garments to be draped on the avatars while changing the avatar’s measurements and body shape as little as possible. To protect participant’s identities, details of the face were smoothed in ZBrush. The changes to Subject A’s avatar can be seen in Figure 3 below.

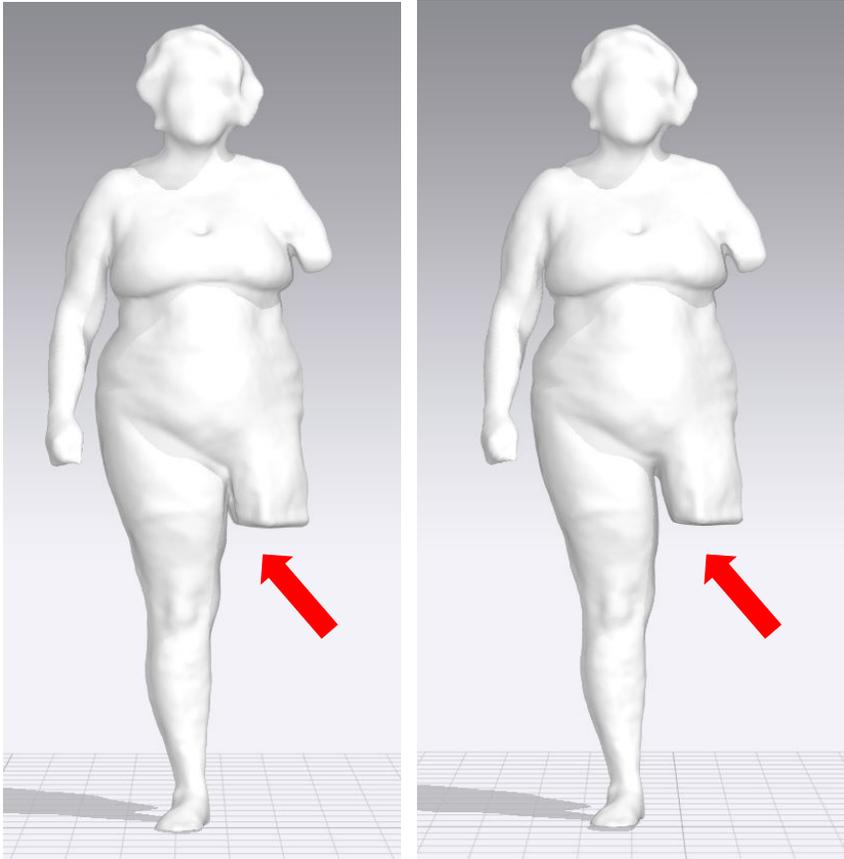


Figure 3. Subject A avatar before editing (left) and after editing (right), showing the removal of excess data between the legs.

Figures 4 and 5 below show front, back and side views of each participant's avatar, the final product of Step 1, as edited (.obj) files imported into the 3D software.



Figure 4. Subject A avatar.

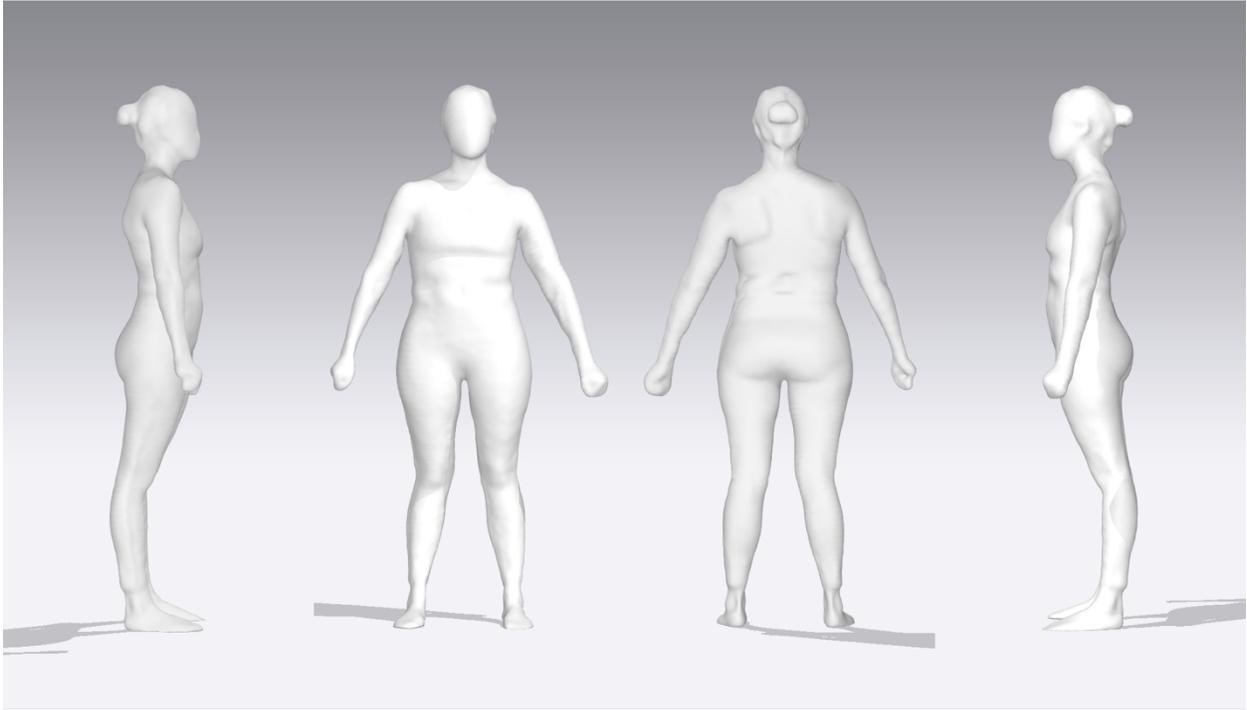


Figure 5. Subject B avatar.

Step 1 is summarized in the process chart below (Figure 6).

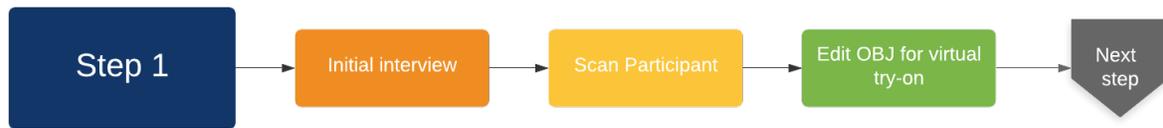


Figure 6. Step 1 process chart.

Challenges in Step 1

As discussed in the literature review, the body scanner had difficulty extracting body measurements and creating an (.obj) from Subject A's point cloud data, because of the way the software was designed. To derive an (.obj) file, the scanner first gathers data in a disorganized dispersion of xyz coordinates within the scanning area, called a point cloud. The scanning software then generates a set of body measurements from this point cloud, which it triangulates into a closed shape of the human form, the (.obj) file. In Subject A's case, the body scanner was not able to generate a set of measurements from Subject A's point cloud, and consequently could not create an (.obj). This was likely due to the scanning software's programming, which was designed to look for a central axis through the body, using the arm and leg positions for guidance. The arm and leg positions are pre-determined by the preferred pose used for scanning, with feet approximately shoulder-width apart and arms away from the body. Subject A was able to stand in the scanning booth, holding one of the scanner's handles, but not in the preferred posture. However, the digital artist on the research team was able to create an avatar from the point cloud using another software, enabling the researcher to proceed with Subject A. Subject B's scanning process was completed without challenges.

Step 2: Altering the patterns in the 3D apparel visualization software

The second step of the framework was to fit the digital patterns on the avatars in the 3D apparel visualization software. Several sub-steps were taken to accomplish this, including selecting patterns, the export and import process, and arranging the patterns in the 3D software. Once each pattern had been simulated on each avatar, virtual fitting could proceed. Details from each of these sub-steps will be reported in the following paragraphs.

Selecting patterns

Pattern blocks, corresponding with ASTM sizing, were selected from digital stock. Two blocks were chosen: an upper body garment with two front and back waist darts, center front closure and center back seam, and a bifurcated lower body garment with two front and back waist darts and a center back closure. To determine which size blocks to use, measurements from the chest, waist and hip of the custom avatars were compared to measurements from the ASTM size chart and measurements taken from the corresponding blocks in the pattern design software (see Table 1 and Table 2 below). As a result of this measurement comparison process, two potential sizes for each participant were considered. Based on the style of the shirt block there were several options for adjusting the waist using the darts and center back seam. It was therefore more efficient to choose blocks that, based on the measurements, would fit approximately at the chest and hip, even if those blocks did not fit at the waist. Therefore, the chest and hip measurements were prioritized over the waist, selecting blocks with approximately two inches of ease in the chest and hip. Using the measurement comparison chart, two inches of ease seemed a reasonable midpoint between the ASTM-assumed body shape and the participant's actual measurements. Comparing the measurements of the blocks and the participants measurements, the blocks

chosen for each participant exhibited tightness around the waist. Size 18 was selected for Subject A and a combination of sizes 8 and 10 were chosen for Subject B (See Table 1 and 2 below).

Table 1. Subject A Measurement Comparison chart

Measurements	Subject A Avatar	ASTM Missy Size 16	ASTM Missy Size 18	Size 18 Block (Shirt)	Size 18 Block (Pant)
Chest/Bust	42.01	42.13	44.00	45.30	-
Waist	38.16	34.50	36.75	36.20	36.87
Hip	46.98	45.00	46.75	-	48.67
Inseam	26.68	-	-	-	-

Table 2. Subject B Measurement Comparison chart

Measurements	Subject E Avatar	ASTM Missy Size 8	ASTM Missy Size 10	Size 8 Block (Shirt)	Size 10 Block (Pant)
Chest/Bust	36.00	36.25	37.25	38.35	-
Waist	33.43	28.00	29.00	27.75	28.82
Hip	40.81	39.25	40.25	-	42.33
Inseam	29.35	-	-	-	-

Exporting patterns from pattern design software into 3D apparel visualization software

Pattern blocks were transferred from the pattern-design software into the 3D apparel visualization program. As discussed previously, this was accomplished by export and import as (.dxf), a type of file used for transferring graphic data between CAD programs. Several steps were needed to prepare the blocks for export. The blocks had been created with the intention of being used for making physical garments, as opposed to virtual garments. This meant they had features needed for physical garment construction that were unnecessary for virtual garment assembly, such as grade rules, seam allowance and system-recognized darts. The seam allowance

and darts had to be removed or modified so the garments could be virtually stitched. The shirt and pant block sizes for each participant were selected from the appropriate size of each block in the pattern design software, then saved into separate models in a folder designated for the research. Grade rules and seam allowances were removed, and the researcher exported each pattern piece individually and created separate files for each garment.

Pattern placement

The next step was to arrange the virtual patterns around the avatar to achieve correct placement when the simulation was run. Parametric avatars available in the 3D apparel visualization software have ‘arrangement points,’ which are predetermined areas pattern pieces can be paired with to partly automate the arrangement process (See Figure 7 below).

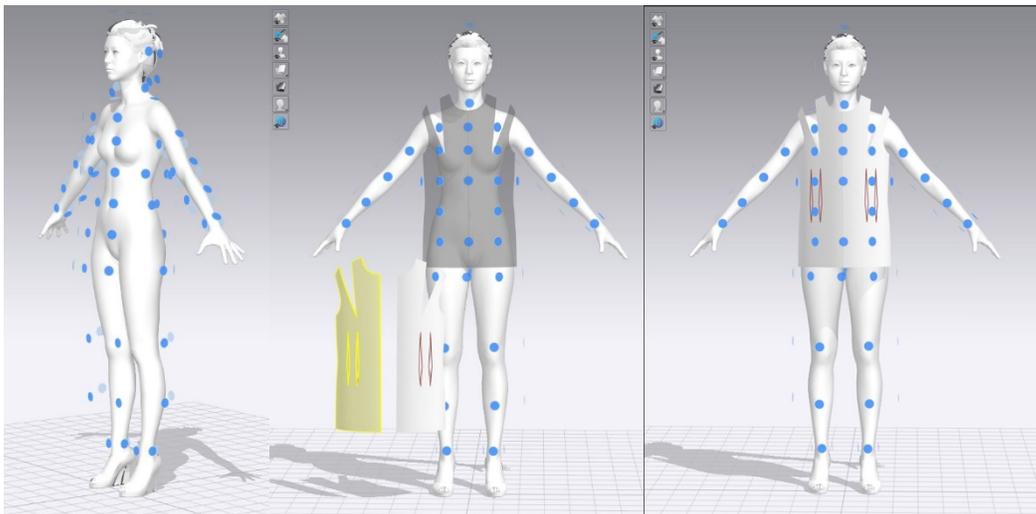


Figure 7. Parametric avatar with arrangement points (left). Placing a pattern using arrangement points (center). Final placement of the pattern on the arrangement points (right).

Custom avatars imported into the program do not have these points, so the researcher explored the options of adding arrangements points or manually placing the patterns. The arrangement points were intended for use with the stock avatars, whose proportions and body position did not match the participants'. Consequently, the arrangement points were misaligned with the participant's avatars and could not be used to place the patterns (Figure 8). Figure 8 below shows Subject A's avatar and the arrangement point configuration in the 3D software. The arrangement points are off-center from the avatar's body, as Subject A's weight was distributed over one leg. The stock avatar was also taller than Subject A, showing the chest and shoulder arrangement points higher than Subject A's chest and shoulders. The arrangement points for the arms are also positioned further from the body than Subject A's avatar shows. Manual repositioning of the arrangement points was possible but would have taken about as much time as manually positioning the pattern pieces. In the case of a one-time virtual fitting with relatively few pattern pieces, moving the arrangement points would not provide benefit in terms of saving time (Figure 8). Figure 8 below shows the process of manually placing the pattern pieces around the avatar.

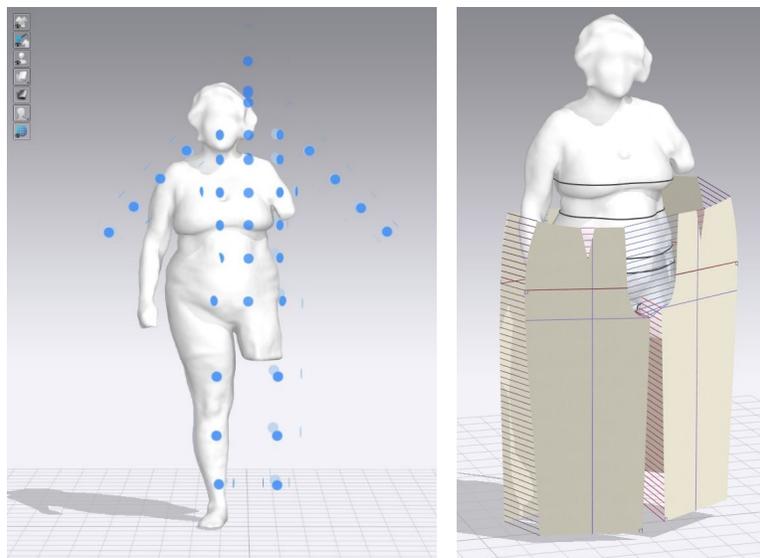


Figure 8. Subject A avatar with misaligned arrangement points (left). Manual arrangement of pant pattern pieces (right).

Virtual fitting

Three tools were used to inform decisions about virtual fit: a visual assessment of the fit based on the researcher's expertise, the strain mapping tool and the fit mapping tool available in the 3D apparel visualization software. Based on prior knowledge about garment fitting and the 3D apparel visualization program, the researcher planned to employ the following basic procedures to conduct the virtual fittings:

1. Work to stabilize the garment simulations on each avatar.
2. Make a visual assessment of the garment fit and plan alterations accordingly.
3. Fit the garment starting from the highest point of that garment i.e. from the shoulders of the shirt and the waist of the pants.
4. Attempt to verify the alterations using virtual fitting tools.
5. Reassess the garment fit and determine whether further alterations are needed.

Background information about the virtual fitting tools will be provided in this section with an explanation of how these tools were expected to be used in this research. The virtual environment offers several tools intended to aid product developers in fitting garments, including strain and fit maps. The strain map is a color-coded mesh that appears over the garment's surface to show areas where the fabric is under strain (Figure 9). The colors refer to the degree of strain on the fabric, with red indicating the most strain and blue indicating the least. Fabric strain may be due to interaction with the avatar or other garment features, to the virtual sewing or other factors (Sayem, 2017). The fit map tool is intended to show areas where the garment is tight or is unable to be worn due to tightness. This tool causes any virtual fabric texture or color to be obscured, showing the fabric in white, with tight areas in yellow and unwearable areas in red.

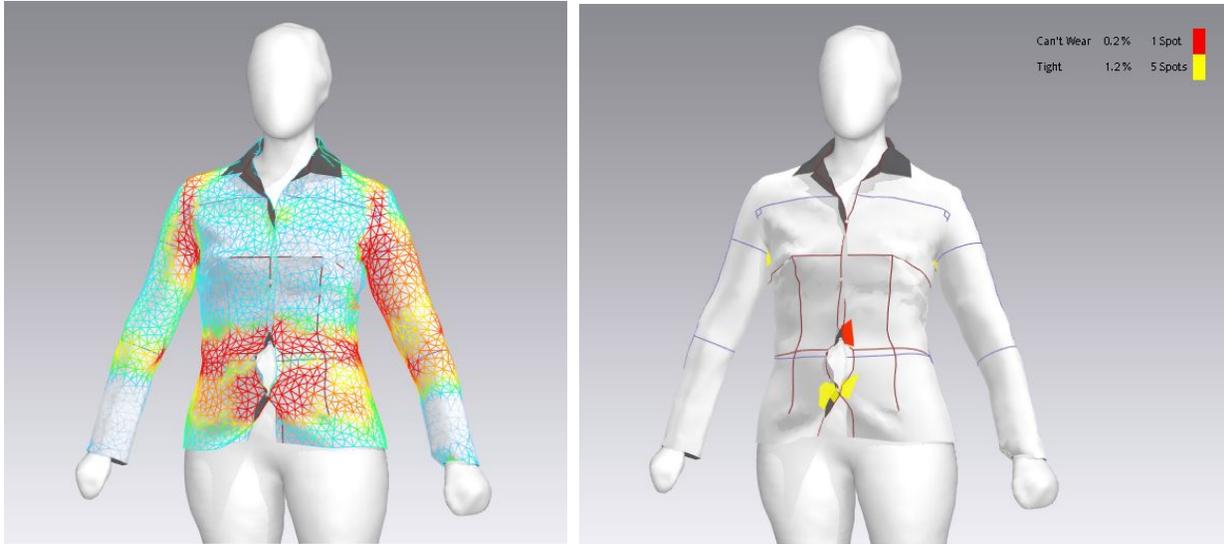


Figure 9. Strain map of Subject E original shirt pattern (left), fit map of Subject E original pattern (right).

Based on information from the measurement charts which compared the avatar measurements to the pattern measurements, all garments started with strain in the waist area. With the basic procedures for the fittings mentioned above, each fitting began with an assessment of the garment fit, once the garment simulation had stabilized on the avatar. Next, the strain and fit mapping tools were employed to identify unwearable, tight or strained areas, which would help in planning where and how to alter the garments. After making the planned alterations, the strain and fit mapping tools were referred to again, to help assess the efficacy of the alterations. Last, a decision was made whether further alterations would be needed based on a visual assessment and reference to the virtual fitting tools. An example of the output of Step 2 is shown in the figures below, which compare the original to the final virtual garments, showing the results of the adjustments made to each garment. The following Figures 10-16 show the original pattern of Subject A's shirt (top image) and the final pattern, after virtual alterations had been made (bottom image). First, Subject A's is shown in the normal fabric view, then the strain maps and fit maps are shown. These images show reductions in fabric strain and elimination of unwearable

and tight areas in the garments, per the plan for making alterations discussed above. The images from each of the other garments fit in this study can be seen in Appendix E.

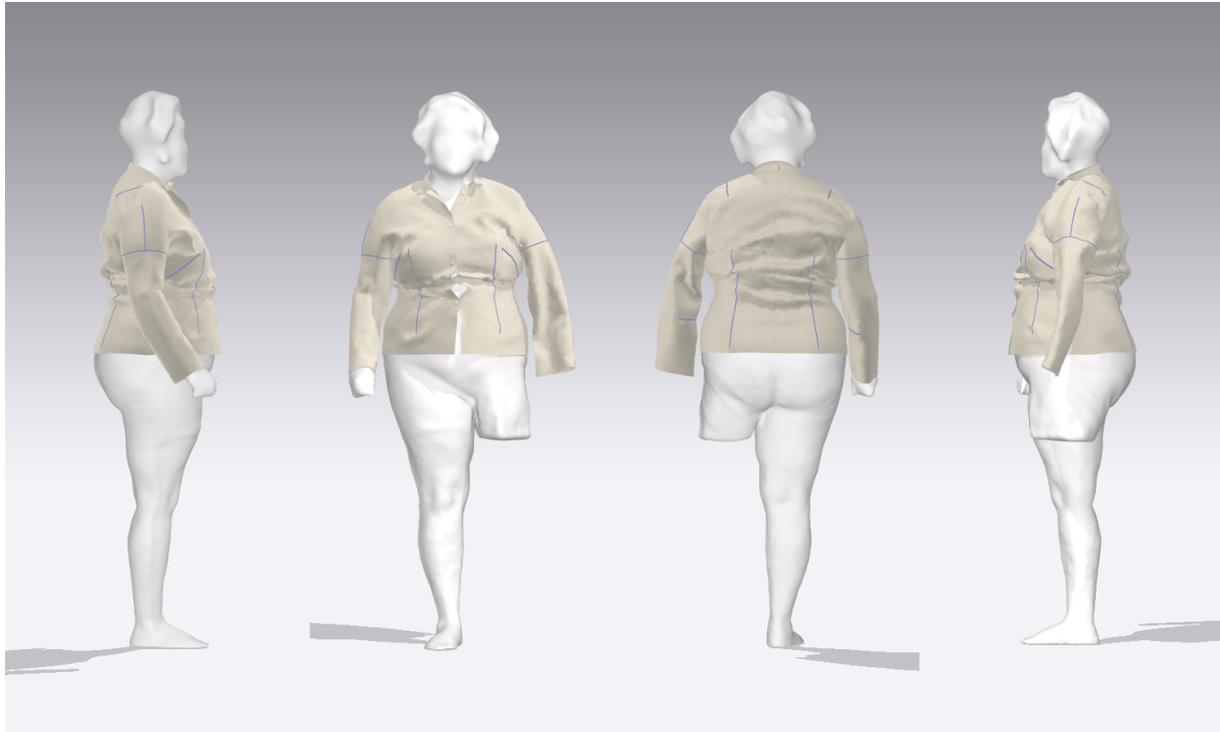


Figure 10. Subject A original shirt pattern, normal fabric view.

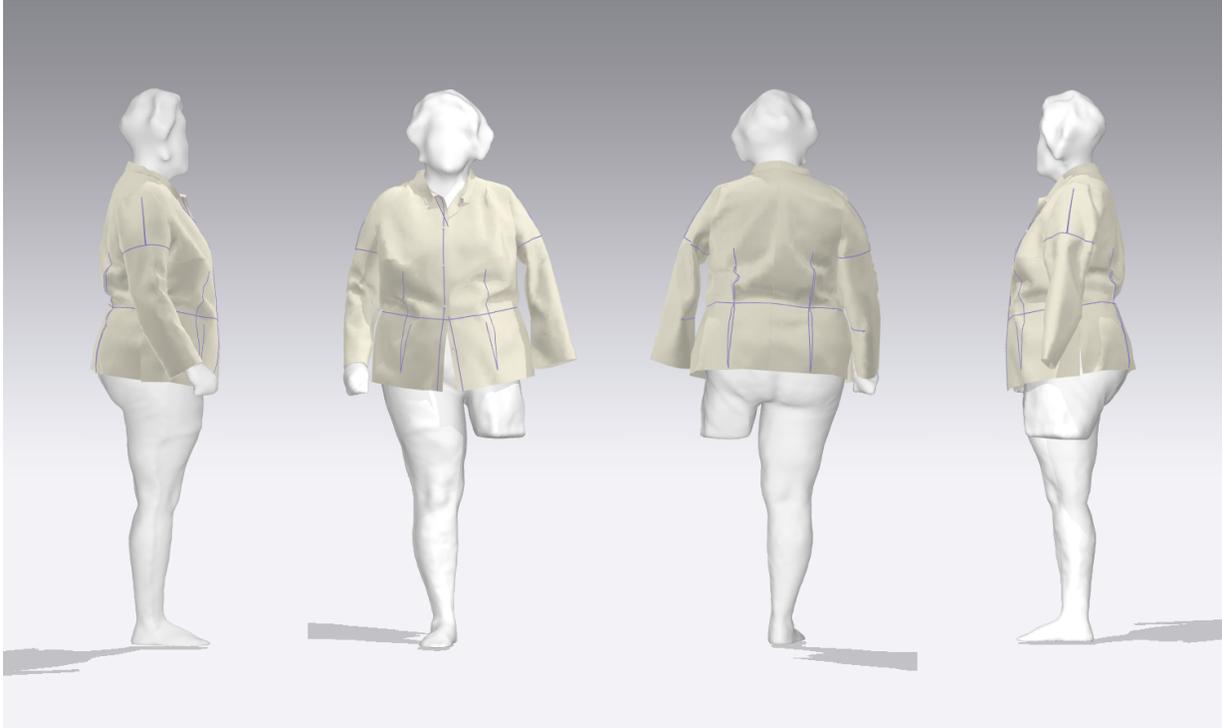


Figure 11. Subject A final shirt pattern, normal fabric view.

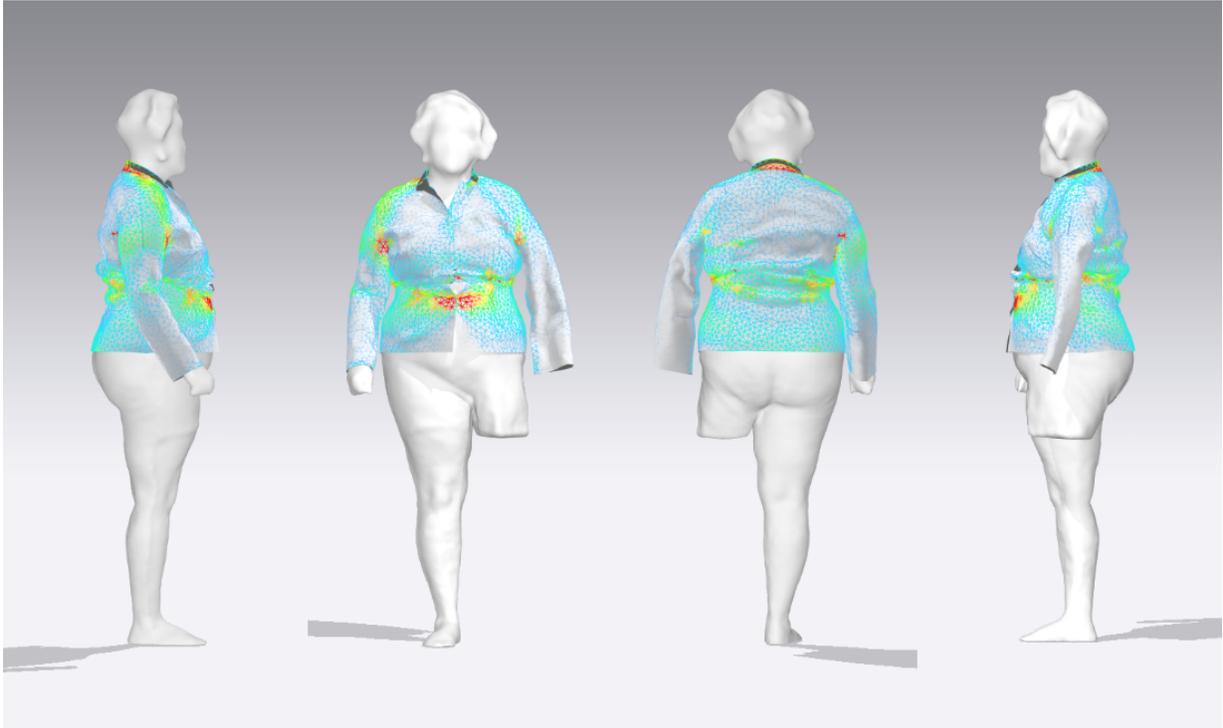


Figure 12. Subject A original shirt, strain map view.

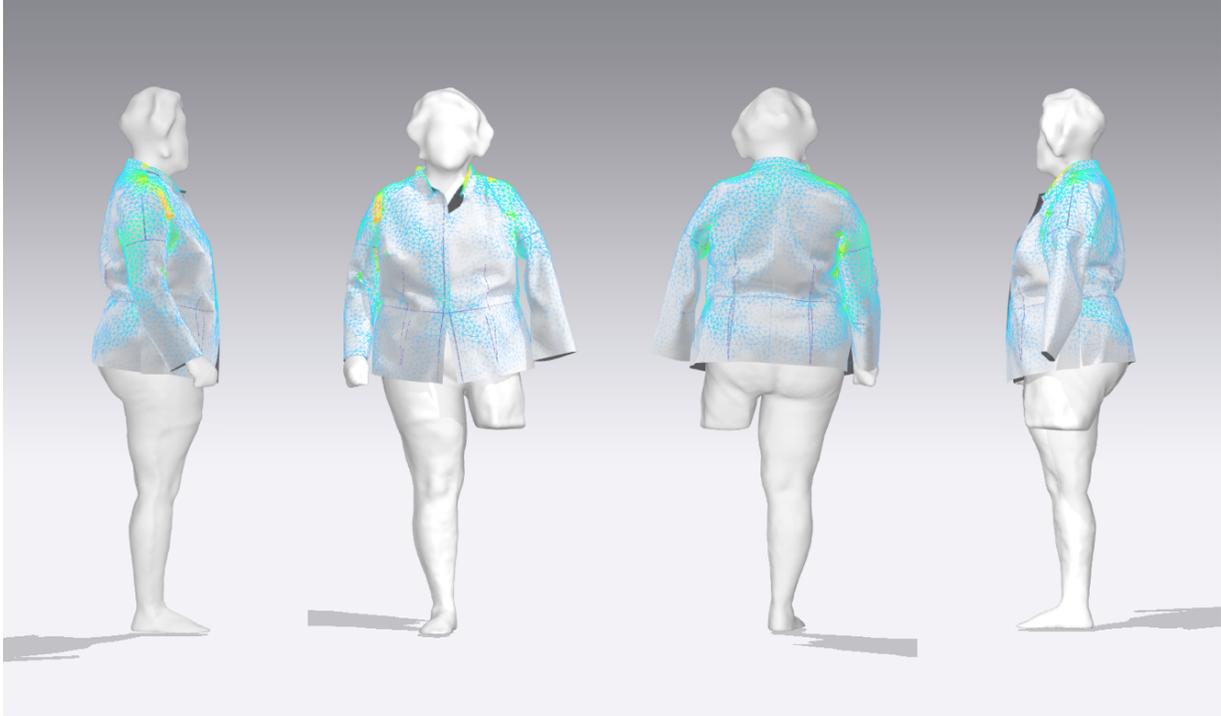


Figure 13. Subject A final shirt, strain map view.

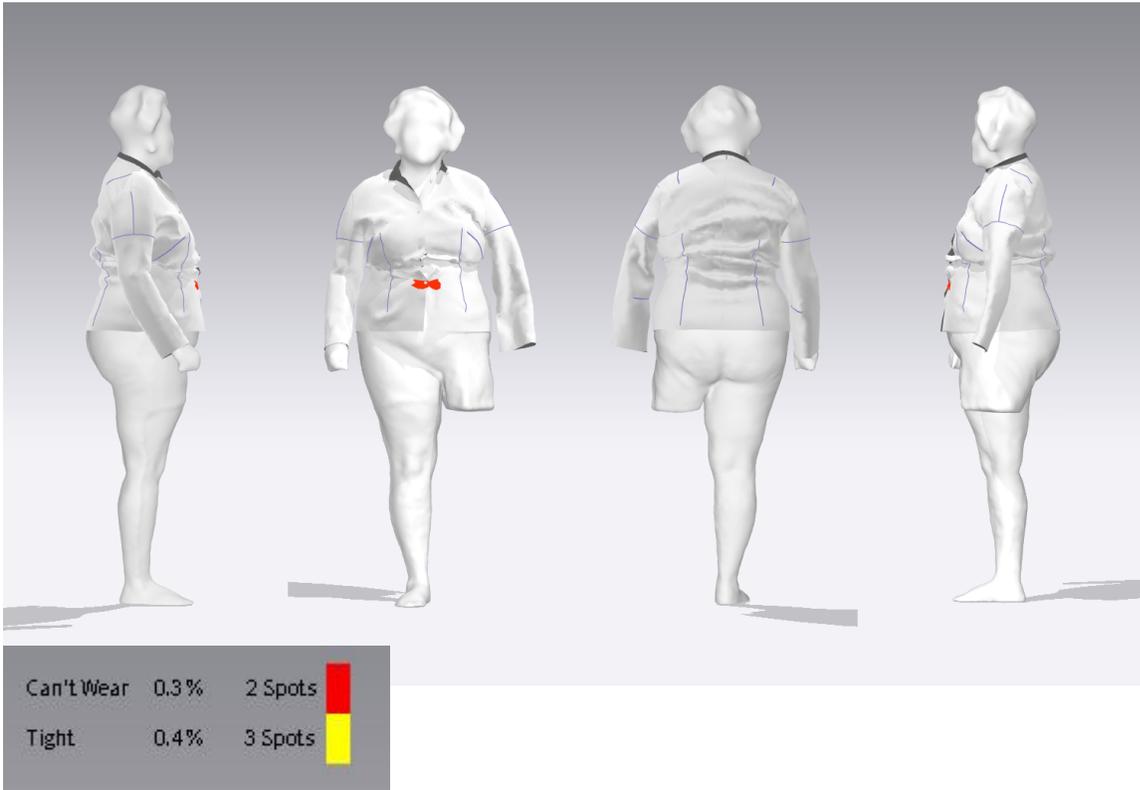


Figure 14. Subject A original shirt, fit map view (top) and fit map scale (bottom).

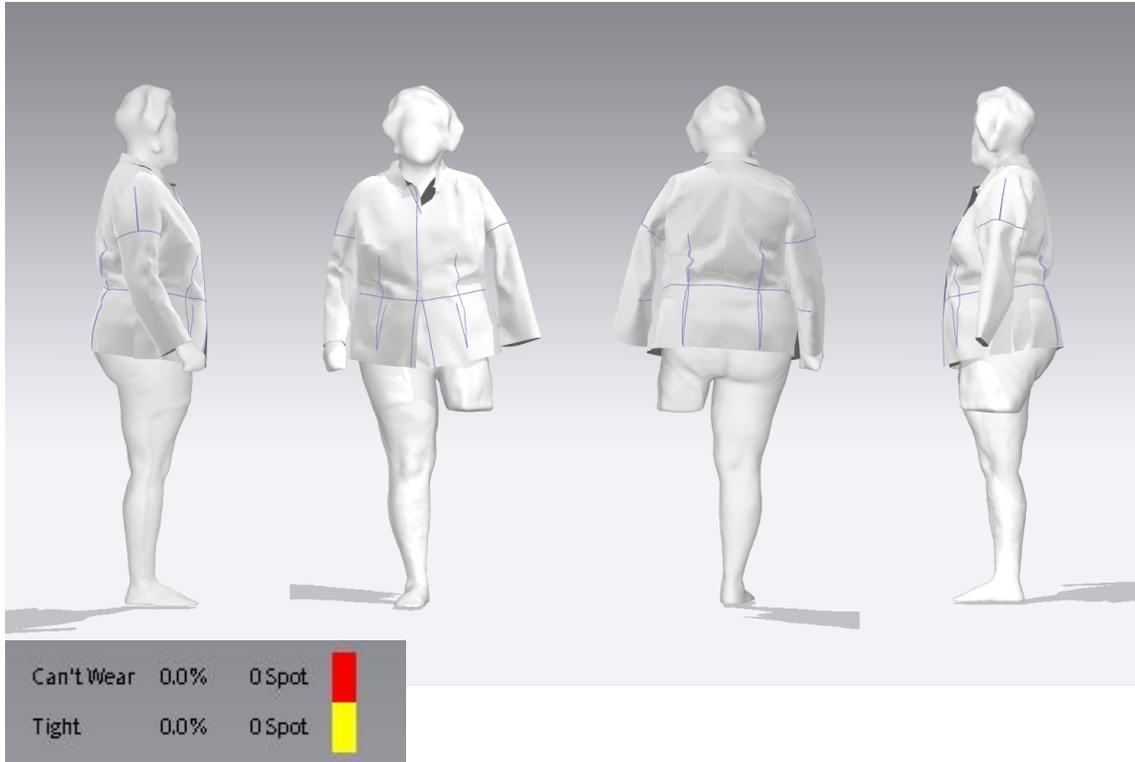


Figure 15. Subject A final shirt, fit map view (top) and fit map scale (bottom).

Figure 16 below shows the Step 2 process, based on notes from this stage of the research.

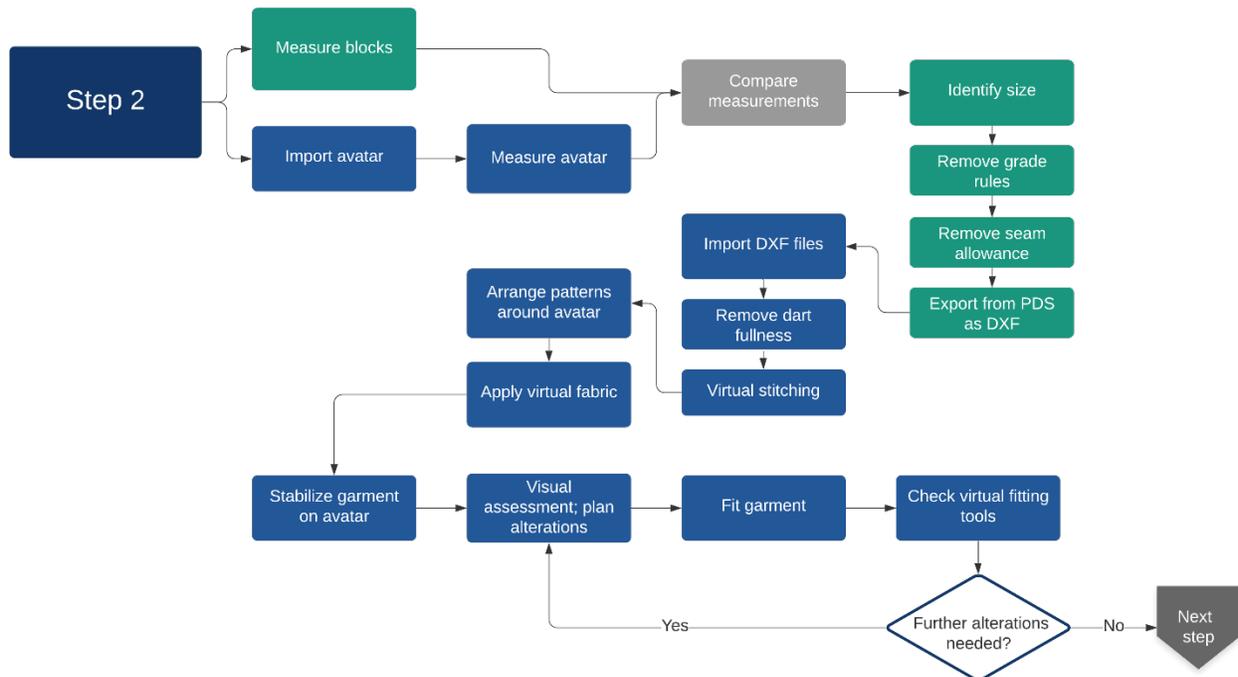


Figure 16. Step 2 process chart.

Challenges in Step 2

Challenges in altering the patterns with the 3D apparel visualization software fell into two categories: the garment position and garment fit. Challenges with garment position occurred during the first step of the alteration processes for the virtual pants and related to the process of stabilizing the garment simulations on each avatar. Challenges with garment fit were encountered during the second step of virtual alterations, in the fitting of Subject B's shirt, related to accommodating the avatar's shoulder and back asymmetry. The following paragraphs will detail these challenges and the process for working through them.

Garment Position

Challenges with virtual fitting related to garment position on the avatar were encountered during the pant fittings. Fitting pants in the virtual environment is different from fitting pants in real life, because actual fabric often has enough stability for the garment to hold itself in position even if there is a lot of ease in the waist. Virtual fabric does not necessarily behave that same way, as it may tend to ride up or slide down the body, in a way that a real garment would not. Upon stitching and simulating the virtual pants for each participant, the pant waist tended to travel up and down the avatar, depending on the amount of ease in the pattern. When the pant waist measurement was very close to or slightly less than the avatar waist measurement at the beginning of virtual fitting, the pants would slide up the avatar's waist until they stabilized at a point higher than the intended rise (Figure 35). When the pant waist measurement had been increased to include ease, the pants would slide down the avatar's waist to a point lower than the intended rise. Additionally, the pants tended to stabilize at slightly different positions on the waist each time the simulation was stopped and restarted. Without a relatively stable waist

position, assessing the virtual fit and determining what alterations were needed was quite difficult. The result of this issue was twofold, causing confusion about the ‘correct’ waist position as the simulation continued to move, and impacting the process as researcher had to take additional steps to identify the waist position and employ tools to hold the pant waist at the desired position. To determine the waist position, the researcher referred to the pattern and avatar measurements and the strain map, and hid part of the virtual garment to see the appearance of the rise seam. The researcher then added a horizontal line to the avatar’s waist for reference (Figure 17).

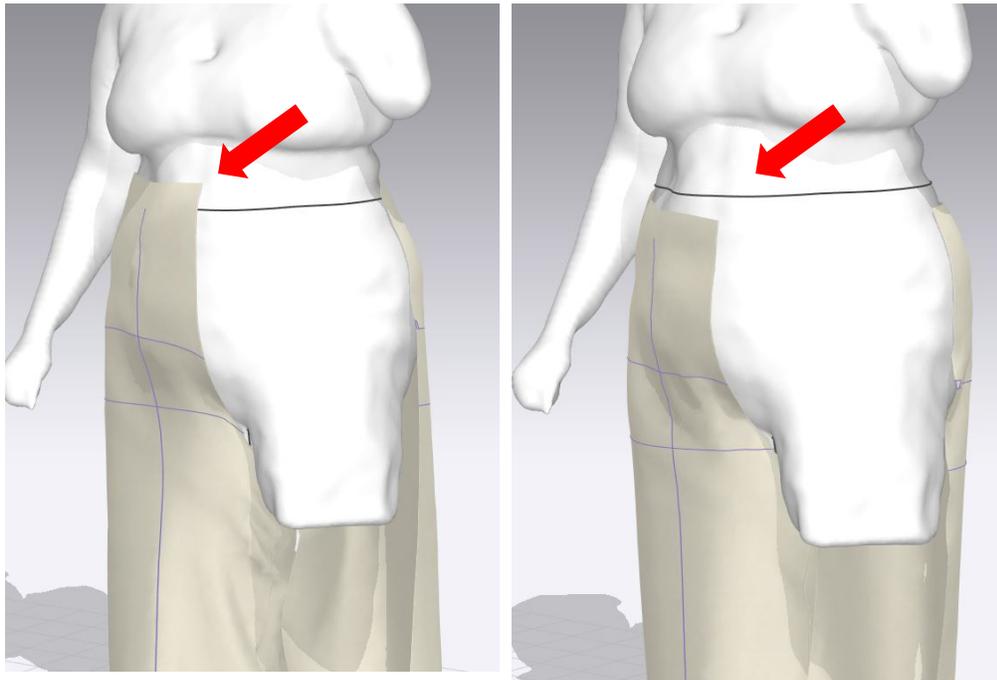


Figure 17. Subject A pant too high (left) and too low (right). Waist reference line in black.

Once the waist position was identified however, the remaining issue was how to keep the pant waist at that position. Options for increasing virtual fabric stability were to use tools such as virtual seam tape or virtual elastic. These tools can be applied to pattern edges or internal lines to prevent stretching or to create the impression of gathering. Virtual elastic was applied to the pant

waist and adjusted the tightness until the virtual pant waist stabilized at the position indicated by the reference line, without causing gathers (See Figure 18 and 19). The virtual elastic was found to be effective in keeping the pant waist at the waist position on the avatar, and that it impacted the appearance of the virtual fit. Figures 18 and 19 show differences in the virtual fabric drape with and without virtual elastic.

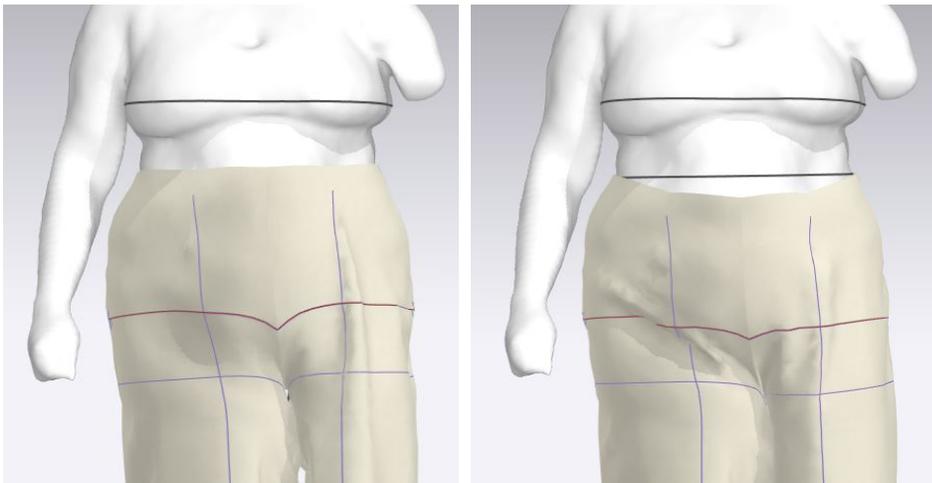


Figure 18. Subject A original pant with virtual elastic (left) and without virtual elastic (right).

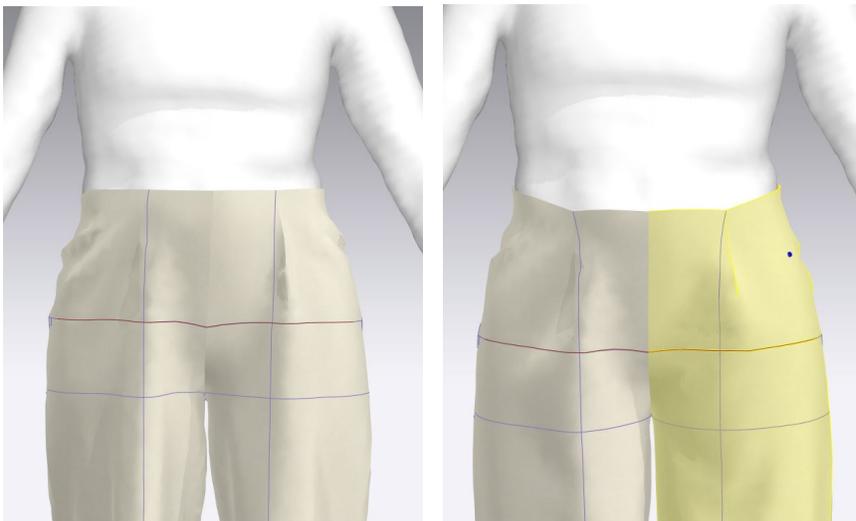


Figure 19. Subject B original pant with virtual elastic (left) and without virtual elastic (right).

Fitting garments: Subject B's shirt

The tailored style of the selected shirt design necessitated some attention to the fit of the shirt in relation to Subject B's shoulder and back asymmetry. The tightness around the waist was addressed first, then the individual adjustments to each side of the shoulders were made. There were still some issues with folds on the back of the shirt, so two different methods were attempted to resolve them. First, the shapes of each fold were traced to show areas of excess fabric and split the pattern along these lines, to remove the excess fabric and merge the pattern pieces back together (See Figure 20 below). This strategy proved unsuccessful, as the pieces could not be merged while maintaining the dart's positions and fullness. The second strategy involved adjusting the center back seam to better accommodate the shoulder blade asymmetry as suggested in the literature (Hong et al, 2018; Hernandez, 2000). These adjustments are shown in Figure 21 below; several attempts were made to make the center back seam hang as straight as possible while minimizing folds in the fabric.

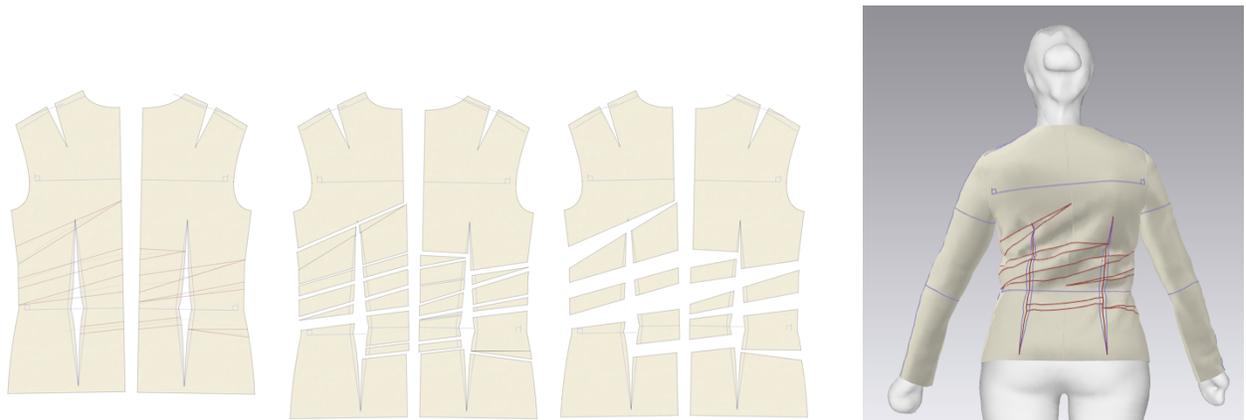


Figure 20. Tracing the folds of Subject B shirt back (right), splitting the pattern (left).

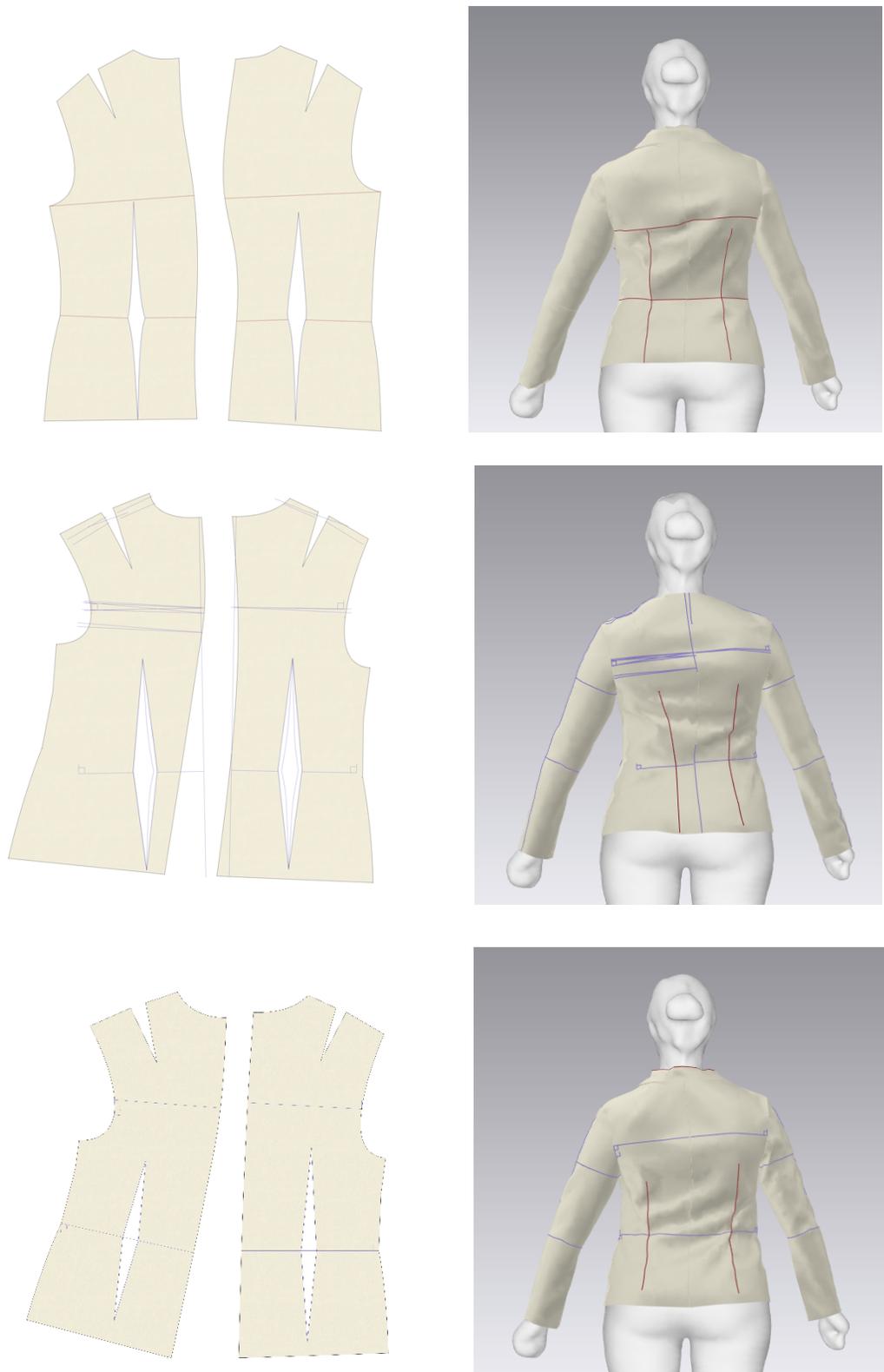


Figure 21. Several attempts at adjusting center back of Subject B shirt pattern (left), resulting appearance of shirt (right).

Step 3: Review garments & avatars with participants

The third step of the framework was to review the avatars, virtual garments and physical garments with each participant. Three sub-steps were taken to accomplish this: patterns were prepared to be cut, physical garment samples were made, and the participants returned for a second research session to view their avatars and virtual garments, and to try on their physical garment samples. Details from these steps are reported in the following paragraphs.

Preparing the patterns for cutting

The next step of the process involved all the procedures necessary to prepare the patterns to be cut on an industrial cutter. To do this, patterns were exported from the 3D apparel visualization software to the pattern design software, modified and made into a marker for cutting.

Modifications to the darts were completed first; darts with fullness arranged at the edges of the patterns are cut out in the 3D apparel visualization software and were converted into system-recognized darts in the pattern design software. This stage of the process did not present challenges, so much as require a work-around strategy to maintain the dart placements, which were altered significantly in Subject B's shirt. Fisheye darts shaping the shirt waists were marked with pattern design software functions for Subject A's shirt, in which the darts were aligned with the fabric grain. For Subject B's shirt, which had off-grain, asymmetrical fisheye darts shaping the waist, the regular dart functions could not be used. Instead, the researcher marked the four dart endpoints with drill holes so their shape and position could be maintained.

Making the garments

The industry term for making garments is “cut, make and trim,” which means cutting out the patterns, sewing them together and adding closures or finishing details not included on the pattern. These were the basic objectives of this stage of the framework, the first of which was to cut each garment. The researcher opted to use 60s weight muslin, a type of lightweight woven cotton fabric, for the physical garment samples because it is frequently used in research and industry for sampling, is inexpensive and widely available. The next step was the sewing process. The garment pieces were stitched with a basting stitch, with sleeves sewn into tubes but not attached to the armholes. The garments were made to be pin fit, with extra seam allowance at the center back seam of the pants. The shirt opened at center front, with stitch lines marked with pen indicating pinning locations. This was intended to correspond with the traditional fitting practice of checking the body of the garment fit before adding the sleeves.

Reviewing the garments and avatars with the participants.

This stage of the process entailed asking the participants to return for another research session, the goal of which was a) to allow them to view their virtual garments and their avatar, try on their physical garments and b) to gather interview data on their responses to the garments and the avatars. During these sessions, the participants were first shown the avatar that had been developed from their body scan wearing the virtual garments. The custom avatars had monochromatic white surface textures and were shown to the participants in the 3D apparel visualization software environment, which had a grey gradient background and grid plane onto which the avatars were placed. Figure 22 below shows examples of the avatars and virtual garments in different views within the 3D software, as they were shown to the participants. The

garments and avatars could be viewed from any angle, zoomed in and out, and with the virtual garments shown, partially hidden, or fully hidden. The display could include the patterns, the patterns and avatar, or the avatar alone.

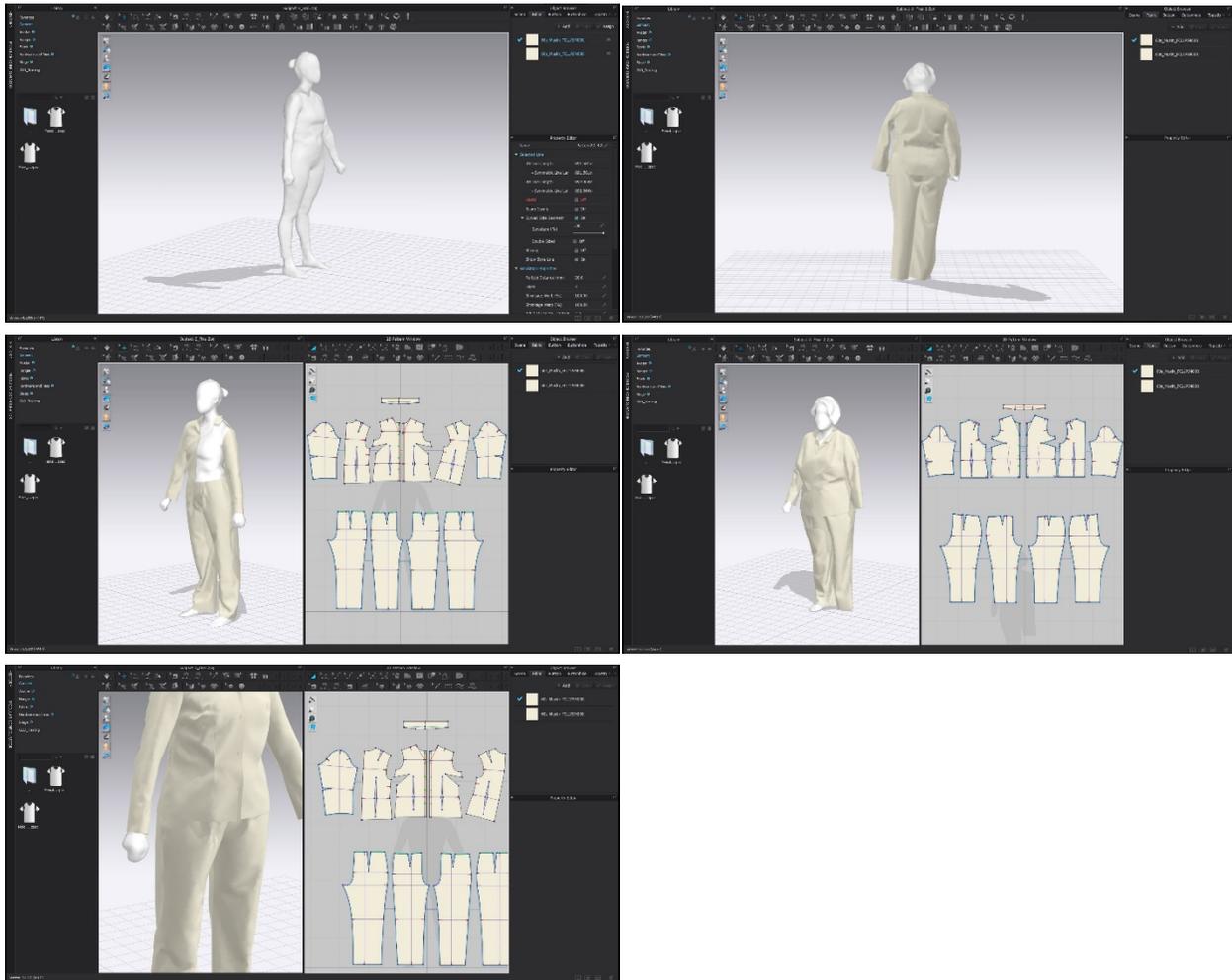


Figure 22. Viewing options in the 3D apparel visualization software.

The participants were then asked a series of questions (Appendix D), which were used to gather information about the participant's reactions to their avatar independent from their reaction to the avatar dressed in virtual garments and their overall reaction to the software. After viewing the virtual garments, the participants tried on their physical garment samples to compare the reactions to the real and virtual garments, the same set of questions was asked about the physical

samples as the virtual samples. Figures 23 and 24 below show each participant wearing their sample garments.



Figure 23. Subject A front, back and side views of garments.



Figure 24. Subject B front, back and side views of garments.

Figure 25 below shows the Step 3 process from notes taken during this stage of the research.

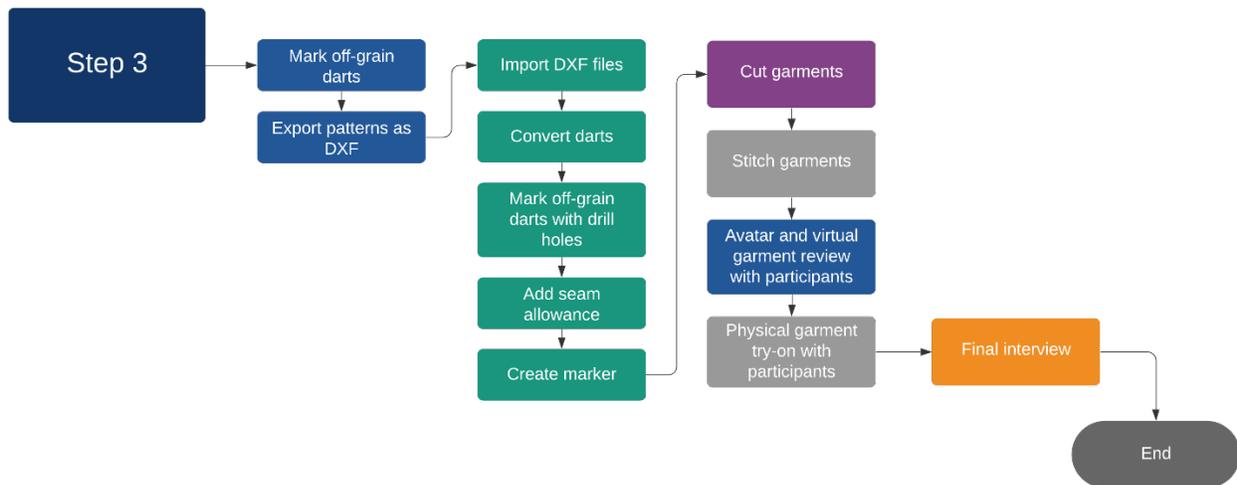


Figure 25. Step 3 process chart.

Section 2: Participant response to the technology

This section will report and discuss findings on the participant's responses to their custom avatars and virtual fitting. As this was a preliminary study with a small sample of participants, conclusions about the whole population of people with disabilities cannot be substantiated. However, this preliminary data will contextualize findings from this research with existing literature. This section begins with brief descriptions of each participant, followed by a description of the way the avatars were edited and presented to the participants in this research to provide context for participant responses. Then the way the participant response data from the interviews was coded and analyzed will be described. Findings from this section fall into five categories: response to avatar, response to the 3D apparel visualization software, perception of virtual garments, perception of physical garments and comparison of response to virtual and physical fit.

Participant Descriptions

Subject A was a woman in her forties who lost part of her left arm and left leg after a car accident. She used a wheelchair most of the time in her daily life. She described herself as a practical person and expressed a need for simple clothing that was easy to wear and maintain. When asked which aspects of clothing (function, comfort, style, easy care, price, other) were most and least important to her, Subject A identified comfort as most important and style as least important. Subject A specified several apparel items she had difficulties with, including regular bras, buttons and zippers, which she could not fasten one-handed. She also said she would like to have a few more clothing options and indicated that she understood what she needed but often could not find suitable options.

Subject B was a graduate student in her thirties who had scoliosis. She described her condition: “I have scoliosis. It was diagnosed in middle school. It is also twisted, so a brace would not have worked for me. You can see a hump on my back, and my shoulders and hips are out of alignment.” When asked which aspects of clothing (function, comfort, style, easy care, price, other) were most and least important to her, Subject B identified style and price as most important and function as least important. Subject B described herself as easy-going and preferred to dress casually. She reported difficulties with professional and formal attire; jackets, button-down shirts and certain dress styles tended to be uncomfortable and fit poorly. Subject B expressed interest in having custom garments made, especially a garment made to accommodate her uneven shoulders and back.

Response to avatars

When asked for an opinion about their avatar, each participant expressed discomfort with their own appearances in the software and with the novelty of viewing themselves in this context. These feelings supported findings from the literature, in which some participants showed discomfort or distress with their avatar's appearance (Kim & LaBat, 2012; Loker et al, 2004; Grogan et al, 2016; Ridgeway, 2017). Subject A laughingly compared the experience of looking at her avatar to being in a dressing room with multiple mirrors, saying "It's like the mirrors in the changing rooms at the store, so you can see yourself from the back," but expressed her discomfort by saying "I'm not putting so many mirrors in my house." Subject A also indicated that she perceived the avatar's appearance as older than her own: "It's the first time seeing my body like that. I look just like my grandmother; I remember from when I was a kid she looked exactly like that. I suppose I have her body type." Subject B also expressed dissatisfaction with her avatar's appearance, saying "I think I look large. Does it make everybody look ten pounds heavier? I mean, I've just never looked at myself like this before...it [the avatar] looks lumpy and large." Subject B also commented that she did not think her avatar showed any muscle definition, and that the avatar did not match her perception of her own appearance in some ways, "It [the avatar] doesn't show any muscle definition...I know for sure my knees are not that lumpy."

Studies discussed in the literature also indicated a tendency for customers to feel that the avatars provided an accurate or objective view of their body (Loker et al, 2004; Grogan et al, 2016). Both subjects made comments that relate to this finding. Subject A said, "When you first look at the avatar, you just look at your body, the way it looks for real." Subject B said "I think it

provides more of an objective view of the disability proportions.” In Subject B’s case, this seemed to be a positive insight. Subject B commented that the avatar showed her body from a different perspective than she’d ever seen before, changing her perception of features that she considered noticeable. After looking carefully at the avatar’s back and shoulders, Subject E said:

In my mind, the slump and the hump on my back are much more pronounced than they appear here. I always thought my shoulder was the most noticeable thing but on this [the avatar] I notice my hips being out of balance more. That crease in my stomach is because I’m leaning toward one hip and I see that in the mirror but I just didn’t think it was that noticeable. But maybe it’s just not as noticeable in real life as I think it is. It’s kind of nice to know that it’s not as big as I think it is. I always think the difference in my shoulder height is also a lot more pronounced. It’s nice, I guess, that other people don’t notice as much.

The dichotomy in Subject E’s reaction to her avatar shows a more nuanced perception than some of the literature provided. She made several negative comments about her avatar’s appearance but was also able to see that her body asymmetry may be less noticeable to others than she had previously believed.

Subject B also noticed the shapes of the garments she had worn during body scanning.

Participants were asked to wear tight-fitting clothes for the scan; areas on the ankles, back and hips where the scan garments either cut into or stood away from the body, causing indentations and irregularities to appear (Figures 26 and 27 below). Subject B noted these discrepancies, saying “I can see the definition of the clothing I was wearing, the outline of the sports bra I was wearing.” Irregularities in the avatar’s surface caused by the garments may have contributed to

Subject B’s impression of her avatar. Although Subject A made no comments about being able to see the impression of the garments she wore, irregularities caused by the garments are also clearly shown on her avatar (Figure 27).

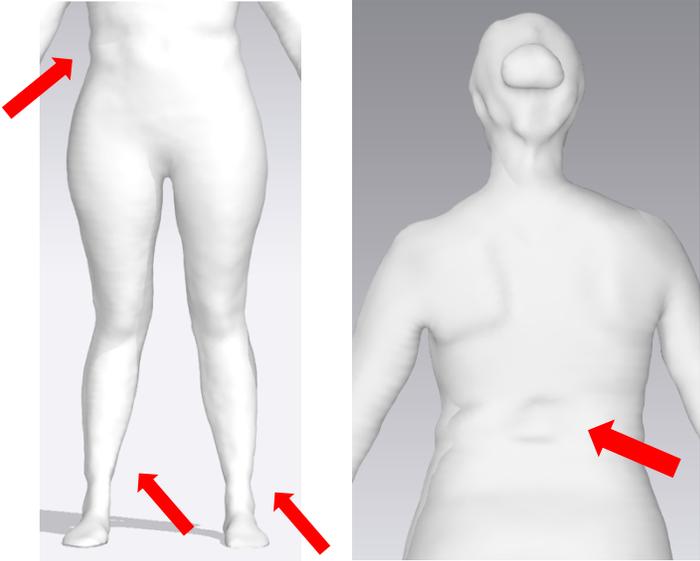


Figure 26. Subject B avatar showing impressions of leggings on the waist and ankles (left) and back (right).

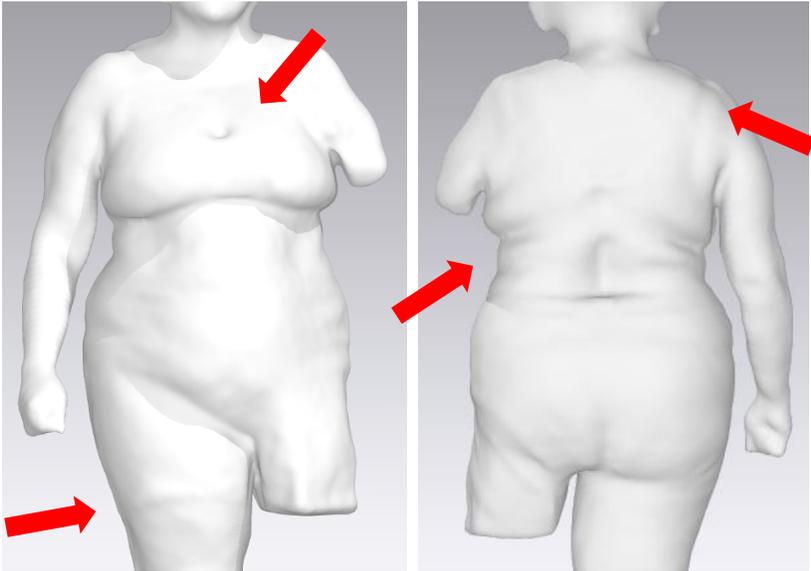


Figure 27. Subject A avatar showing impressions of shorts on chest, waist and leg (left) shoulders and back (right).

Response to the 3D apparel visualization software

As shown in previous studies, both participants also had a more positive reaction to the software itself than to their own digital likeness (Kim & LaBat, 2012; Loker et al, 2004; Grogan et al, 2016; Ridgeway, 2017). In response to the body scanning process and the experience of interacting with her avatar, Subject A said “I’m going to be honest; it was super fun. The scan was easy, and it was exciting, you know? It would be awesome to have this technology online.” Subject A also said she “love[d] the [3D apparel visualization] software,” and that if the avatar were available on the websites of stores she shopped at, she would use it a lot because it would save her time as compared to driving to the store. Subject B said she “could see how [3D apparel visualization software] would be really helpful for someone with a more pronounced posture difference,” than herself and it would be “wonderful if the software could be used to arrange [garment] features according to the way [her] body is.” These comments indicate that participants might consider using 3D apparel visualization technology despite the negative impression of their avatars, if the technology were presented to them in a manner they considered useful.

Perception of Virtual Garments

When asked for a general impression of the virtual garments, neither participant felt certain what type of garment the virtual samples were. Subject A assumed the shirt was a jacket, and the garments were a suit. Subject B asked for clarification as to what the garments were, “Is it a top and bottom? Are they slacks, pajamas...?” The participants were then asked for an overall impression of the fit of the virtual garments. Based on the participant’s responses, the research team found that consumer perception of fit is subjective (Song & Ashdown, 2010, Ashdown et

al, 2007), and that these perceptions impacted the participant's responses to their garments. Each participant had a different idea of what a good fit entailed: Subject A preferred looser garments and a more relaxed fit, while Subject B favored more fitted garments.

Subject A: What I look for first is comfort. I'm a very practical person...I try to keep it quick and easy. I cannot do super-tight options, so I usually buy the biggest pants I can find, or I use men's shorts. The [virtual] pants look good and comfortable, that's a big priority to me.

Subject B: Normally I'd wear tighter slacks, because wider pants draw my eye to my hips, but tapered pants draws more attention to my legs being thinner. I kind of have a rectangle figure and there's not much natural definition of my waist, so I'd prefer the [shirt] design be tighter there to give that definition.

Subject A was generally more satisfied with both virtual and physical pants than Subject B.

Subject A said "They [the virtual garments] look formal and nice, like for a job interview. I love them, they look comfortable." Subject B, who preferred a slimmer leg silhouette, said "I like that they're tailored to fit me. I can't see a lot of detail, but the [virtual shirt] design looks good."

In response to questions on their general reaction to the virtual garments, both participants showed interest in having their avatars available online for virtual try-on.

Subject A: I would actually love to have these technologies in the stores I like. If we can use these things in the webpages of stores...even going to the store once to scan ourselves and

then having this on the webpage to try on the clothes, that is going to just change all the businesses. I would be using this so much.

Subject B: It's cool how you can see how the garment falls on the body. Models online never show that, but I can see exactly how the clothing would hang on my body with the avatar. The way the clothes fall on the avatar looks very familiar to me, it's really interesting.

Subject B's comment indicates that she recognized some level of similarity between the virtual garment fit and her general experience with the way garments look on herself. It seemed the avatar gave her a more realistic idea of how the actual garments would look when she tried them on, which is information she cannot usually get from shopping online.

Response to physical garments

Both participants had a similar initial response to the physical garments as they did to the virtual ones. Subject A said "I like them, they are super nice and comfortable." When asked for a first impression of the physical garments, Subject B said "I feel the same way I did about the ones on the avatar. I'd like the sleeves shorter and the pant legs narrower. The pants feel like lounging and the shirt is a bit restricting." Both participants were dissatisfied with the darts at the front of the shirts. Subject A requested two waist darts be added to the front of her shirt, and felt that the bust darts were too long. Subject B felt that the bust and waist darts on her shirt front were too long, and that the waist darts were placed too far medially on the shirt fronts.

Comparison of participant response to virtual and physical fit

During the second research session, participants were shown their avatars and virtual garments and asked a set of questions regarding their opinion about the garment fit at eight key points (Appendix D) Then they tried on the physical garment samples and were asked the same set of questions about the garment fit of the physical samples. Table 3 (below) shows a summary of each participant’s response to the fit of the virtual and physical samples based on questions about the garment fit at eight key points. Comparing participant responses to virtual and physical fit indicates whether the virtual garments could be used for consumer fit assessment purposes. This information has implications for online virtual try-on and consumer behavior.

Table 3. Summary of fit responses to virtual and actual garment samples.

	Subject A		Subject B	
Point of Measure	Virtual	Physical	Virtual	Physical
Neck	Good	Good	Good	Good
Shoulders	Good	Good	Good	Good
Chest	Too loose	Too loose	Unsure	Too tight
Sleeves	Good	Too tight	Too long	Too tight, too long
Waist (Shirt)	Too loose	Too loose	Too loose	Too loose
Waist (Pant)	Good	Good	Good	Too loose
Hips	Good	Too loose	Too loose	Too loose
Legs	Too long	Too short	Too loose	Too loose

Subject A had similar responses to the fit of the virtual and physical shirts in four out of five points of measure: the neck, shoulders, chest and waist. She judged both samples to fit well in the neck and shoulders, and to be too loose in the chest and waist. However, she thought the virtual sleeves looked good but felt they were too tight when she tried on her physical shirt sample. There was less agreement on the fit of Subject A’s pant samples. Subject A judged the

pant waist to have a good fit in both the virtual and physical samples. However, she thought the hips looked good in the virtual samples and then decided the physical pant samples were too loose. Subject A also judged the pant legs too long in the virtual sample, but felt they were too short in the physical fitting.

Subject B also gave similar responses to the fit of the virtual and physical shirts in four out of five points of measure: the neck, shoulders, sleeves and waist. She judged both virtual and physical samples to have a good fit at the neck and shoulders and to be too loose at the waist. Subject B felt both the virtual and physical sleeves were too long, but she also did not notice the sleeves were too tight until she tried on her physical shirt sample. Subject B was not able to make a judgement about the fit of the virtual shirt at the chest, but felt the physical shirt was too tight in that area. Additionally, Subject B commented that the collar on her virtual sample was falling differently on each side due to the difference in her shoulder height, and then made the same comment about her physical sample. Subject B responded similarly to the virtual and physical pant samples in two out of three points of measure. Subject B judged the both virtual and actual pants to be too loose through the hips and legs. However, she felt the virtual fit looked good in the pant waist but pointed out some excess ease in the front waist during her physical fitting.

There was some agreement between each participant's opinions on the virtual and actual fit. Both participants felt that the virtual sample fit at the neck and shoulder looked good and responded the same way for the actual samples. Both participants also judged the actual sleeves to be too tight, when neither thought they looked tight in the virtual samples. During their

physical fittings, the participants felt the pants were too short, when they felt the pants were too long in the virtual samples. Both participants wanted more definition in the waist of their shirt samples and both subjects were dissatisfied with the dart placement on the physical garments. The bust point landmark was difficult for the researcher to identify on the avatars, resulting in the darts being too long.

CHAPTER 5

Conclusions & Recommendations

Overview

Conclusions and recommendations from this research relate to the two research objectives, the framework development and the assessment of participant responses to the technology. This section will first discuss conclusions about the framework and then discuss conclusions about participant responses. Recommendations on adjustments to the framework process and avenues for future research will also be included in these sections.

Section 1: Revised framework

This research sought to develop a framework for incorporating 3D apparel visualization software into a computer-aided design process for fitting garments on avatars of people with disabilities. To do this, three basic steps were outlined and conducted with two participants. The process of completing these steps generated a step-by-step chart showing the flow of work between software programs and the specific procedures used to accomplish each task. Additionally, several potential improvements to this process were identified during two steps in the research, which will be discussed in the next sections, illustrated by a revised chart of the process. Areas of improvement for the framework were identified in steps 3 and 4 of the process, in preparing the patterns for simulation and altering the patterns with the 3D software. These improvements fall into three categories: body scan garments, body landmarking and garment fit definition.

Body scan garments

This study found the garments worn by the participants during body scanning in Step 1 to be visible on the avatar surfaces after the avatar editing process, and that one of the study's participants (Subject E) made specific mention of being able to see the garments. In terms of the workflow in this research, two recommendations were identified. Providing garments for the scan or asking consumers to bring a selection of garments for the body scan process and checking the appearance before finishing body scanning may result in avatars with less irregularities caused by the garments. As both participants in this study wore sports bras for their scans which were visible on the avatars, choosing a different style of bra may be better for the purposes of custom avatar creation. Additionally, as both participants were dissatisfied with the shirt front dart placement, a more supportive style of bra may be helpful for fitting purposes. Letting participants know ahead of time that the scan garments may be visible on the finished avatar may help consumers manage their expectations for the avatar's appearance, depending on their choice of garments.

Identify body landmarks on custom avatars

The waist position of the virtual pants was found to be movable within the 3D software, requiring the use of tools in the virtual environment to stabilize the waist position. Both participants' responses to the physical garments showed dissatisfaction with the bust dart placement, indicating the researcher was not able to accurately identify the bust point on the avatars. These findings point to the need to identify and mark body landmark points on custom avatars, like dress forms and parametric stock avatars in the 3D software. Landmark points including the neck, armseye, bust point, waist and hip should be identified on participant's

bodies before the body scan, and marked in such a way that they are visible on the avatar surface. This step should be helpful for product development and fitting purposes. For the purposes of virtually fitting pants, identifying and marking both the natural waist position and the desired rise position of the pants is recommended. In terms of the process, the landmark points and pant rise should be discussed and identified with the participants. Revisions to the framework would occur in Step 1, with body landmarking happening before body scanning. Body landmarking could be done by attaching narrow elastic around the circumference of the body at the chest, waist, pant rise and hips, so that a very slight indentation could be seen on the avatar for the product developer. In terms of marking the bust point, shoulder and neck position, some type of narrow body tape or sticker with enough thickness to be read by the scanner could be employed to identify these positions.

Garment fit definition

Fitting a garment using computer-aided design methods is an iterative process, during which the fit of digital patterns is continually validated by real fittings. The framework developed in this research followed a process similar to industry product development practices, such that the researcher made a set of alterations and reassessed the fit before making further changes. Each garment in this study was altered and assessed between three and six times by the researcher before the physical garment samples were made. However, this study was different from current industry practices in two ways. First, this research included only one physical sample whereas in industry, several samples may be made before a garment is approved for manufacture. Second, current industry use of 3D software mostly involves previously developed patterns that have already been fitted on industry fit models (Mageean & Hanson, 2019). In this study, the

researcher did not have an understanding of how the original patterns fit the participants in reality. This impacted both the visual assessment of virtual fit and the researcher's ability to use the fitting tools as effectively as may be possible with a prior knowledge of garment fit. Starting with a previously established garment fit would be helpful in gauging the changes made with virtual alterations and understanding how the virtual fitting tools relate to the physical garment fit. It is also possible that more experience with the process of using 3D software for making pattern changes for people with body asymmetry may make it easier to assess virtual fit. In the context of this framework, one possible way of gaining an understanding of the original pattern fit on the participants would be to make physical samples of the original patterns and have the participants try them on before the virtual fitting process is completed. This may necessitate having an additional research session with each participant to determine which size patterns to use and allow time for making the samples. If this step was incorporated into the workflow, it would be important to get quality photos of the garments on each participant. As body position and posture has been shown to impact virtual fit, participants would need to stand in the same position for the photos as they would for the body scan. If the participant is not in the same posture for the fit photos and the body scanning, then the appearance of the garment fit in the fit photos would not be comparable to the virtual garment fit on the avatars. Consumers with lower-limb body asymmetry, like Subject A in this research, may need some kind of support device to aid standing in the required pose.

The following chart (Figure 28 below) shows the recommended process based on the framework development in this research.

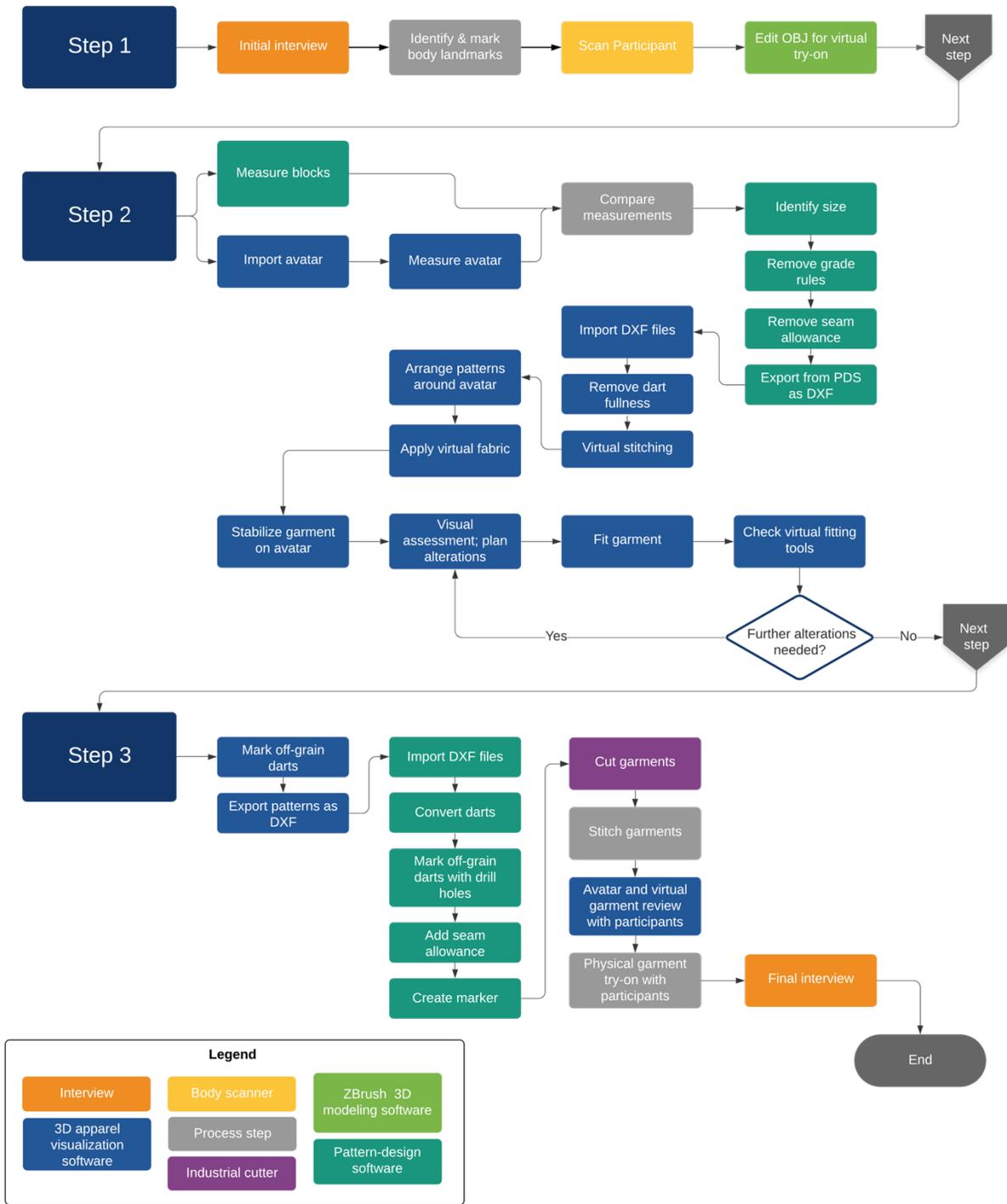


Figure 28. Recommended framework for altering patterns for people with body asymmetry using 3D apparel visualization software.

Framework conclusions & recommendations for future research

From the standpoint of completing RO1, developing the framework, the process followed in this research was successful in that each step was completed for each participant, resulting in two complete sets of data regarding participant apparel preferences and needs, avatar development, virtual alterations and participant response to avatars, virtual garments and physical garments.

The main addition to the post-process framework was landmarking the participant's bodies before body scanning, so that the chest, waist, hips, desired pant rise and bust point would not need to be identified during the virtual fitting. This is shown in Figure 46 above. The process was shown to be a viable way of generating customized garments for people with disabilities, using the tools and equipment chosen for this research. These specific tools, equipment and software programs played major roles in the planning and development of this process.

Completing the process for both participants led to the conclusion that few changes could be made to the process itself without changing the equipment or software being used. Changing the tools would likely result in changes to the process but may not necessarily alter the framework itself in the overall flow of work. One area for future research could involve exploring this process with different combinations of software programs, particularly the 3D software.

Choosing a 3D apparel visualization software with more manufacturing compatibility may provide benefit in terms of streamlining the process, as it could eliminate the need to transfer data between pattern-design and 3D apparel software. However, choosing different programs may create other barriers in the user interface or the ability to make virtual alterations. A framework showing the potential process using a 3D apparel visualization software with pattern-design and manufacturing capabilities is illustrated in Figure 29 below. Another possible avenue for future research is expanding the sample size and inclusion criteria for this process, recruiting

people with other types of disabilities. A larger, more diverse sample would help support the findings in this research and may help to further refine the process.

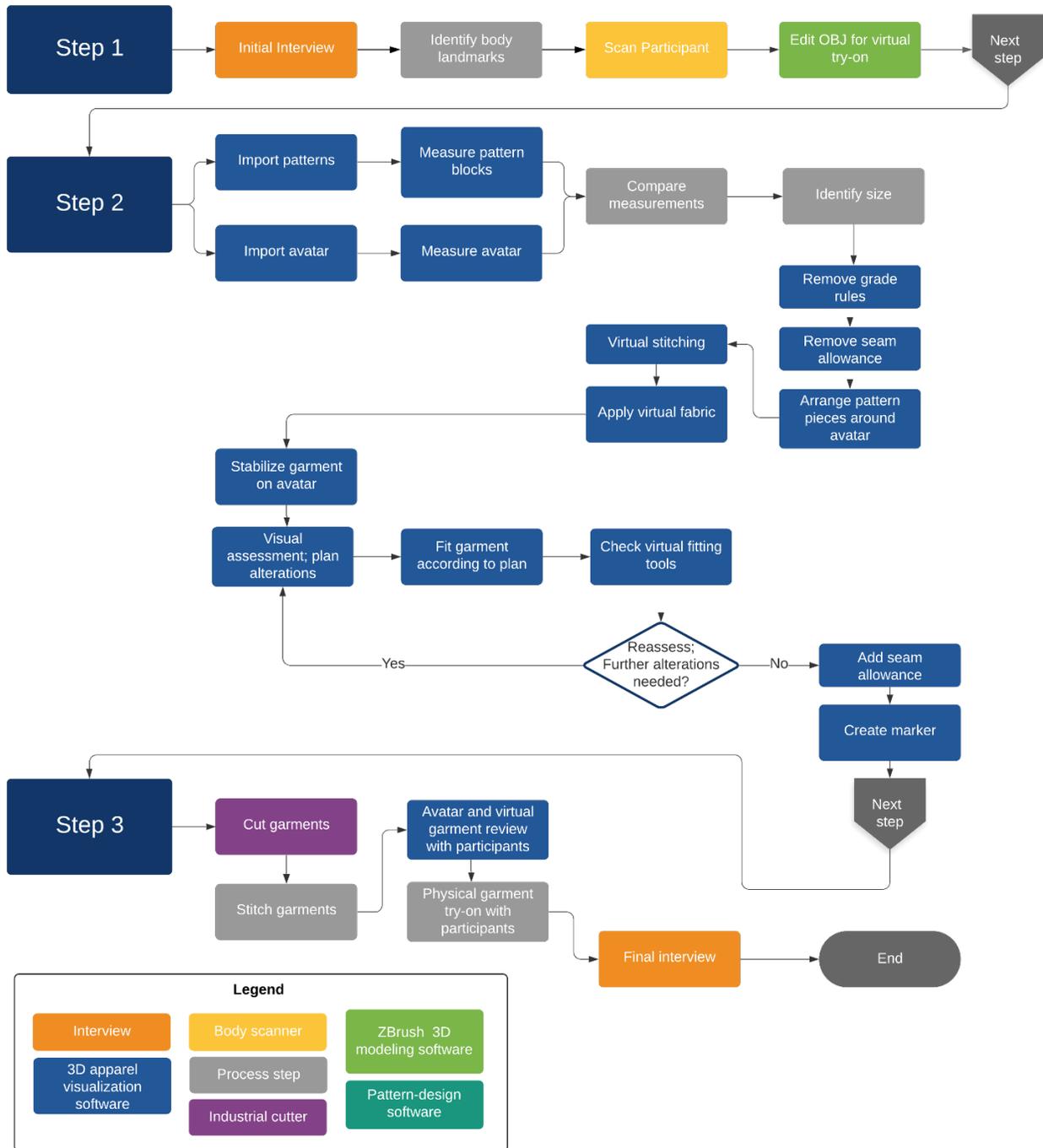


Figure 29. Potential framework using a manufacturing-compatible 3D apparel visualization software.

Section 2: Participant response to the technology

Conclusions regarding participant response to the technology will be reported in two sections, the first discussing participant responses to the avatars and the second reviewing participant responses to the virtual and physical garments. Conclusions regarding participant responses to avatars fall into two categories: factors impacting the participant responses and participant responses contextualized by other research. Conclusions relating to participant response to the virtual and physical garments are in three areas: subjectivity of fit preference, response to the physical garments and comparison of responses to virtual and physical garments. These will be discussed with recommendations for future study in these areas.

Response to avatars

Factors impacting participant response

It is likely that many factors influenced the participant's reactions to their avatars in this study (Loker et al, 2004; Grogan et al, 2016; Ridgeway, 2017). Previous studies have examined response to body scan output and avatars in conjunction with levels of body-image satisfaction, and degree of body-image satisfaction before and after looking at personal body scan data. This research did not gather data related to participant body-image satisfaction and therefore cannot draw conclusions on the relationship between body-image and response to the avatars for the participants in this study. However, based on participant response data, some observations could be made relating to participant body-image and response to avatars. The participants in this study were different from each other in several ways which may have impacted their opinions of their own appearances and their reactions to the avatars. The discrepancy in physical differences was apparent in the participant's opinions about their own appearances. A double amputee and part-

time wheelchair user, Subject A tended to prioritize comfort above other considerations. Some of Subject A's comments indicated that she maintained lower expectations for her appearance: "I am 45 years old, I cannot expect to have...well my friends have that but they are not in my situation." This may suggest that Subject A's perception of her avatar's appearance reflected her expectations, which may have contributed to her relatively higher level of satisfaction with her avatar and virtual garments. Subject B made fewer comments on garment comfort and seemed to have higher expectations for her appearance, possibly because her condition was comparatively less noticeable and caused fewer mobility restrictions. Subject B's comments indicated that her expectations for her avatar's appearance were higher than her perception of that appearance. As she was closer to a 'standard' body type, Subject B may have been accustomed to more clothing options and have higher expectations for her own appearance, making her more likely to be critical of her avatar and virtual garments.

This research revealed some unexpected nuances related to body image in participant perception of the avatars. Although she made several negative comments about her avatar's appearance, Subject B remarked that she could see how the software could be very useful for someone whose body asymmetry was more pronounced than hers; she also commented that looking at her avatar changed her perception of her physical differences. Subject B said that she found the asymmetry in her avatar's shoulders and shoulder blades much less pronounced than she had always believed it to be; she then commented that others may not notice those features as much as she did. These insights lend support to the integration of 3D apparel visualization software in a variety of consumer-related applications for people with body asymmetry, including virtual try-on, custom garment creation and potentially influencing the way people with body asymmetry perceive their appearances. As both participants made comments implying that they felt the

avatars looked larger or older than they did in real life, it is worth considering ways of providing consumers with a sense of their avatars' relative scale and proportion in the virtual environment. Future research could examine ways of making custom avatars more acceptable to consumers by experimenting with different surface textures, backgrounds and finding ways to provide the consumer with a more realistic sense of their avatar's scale.

Response to avatars contextualized by other research

Findings from the participant's responses to their custom avatars indicated a level of discomfort with viewing their avatars in the unfamiliar context of the 3D software and dissatisfaction with their avatar's appearances; at the same time, participants expressed a positive attitude toward the 3D apparel visualization software and an interest in engaging with the software in the future.

These findings are similar to those of previous studies on customer response to viewing personal body scan output, which reported participants were generally more likely to feel comfortable with being body scanned than comfortable with looking at their body scan output (Grogan et al, 2016; Loker et al, 2004; Ridgeway, 2017). It is important to note that while these studies have shown participants images of their personal body scan output, they did not show the scan output in the context of the 3D apparel visualization software, as this study did. Based on the findings from this study, the researcher concluded that the participant response to viewing avatars in the 3D apparel visualization software was similar to the responses previously found to viewing body scan output.

Previous studies on customer response to interacting with 3D apparel visualization software have been limited because participants used computer-generated models that did not necessarily reflect their body size and shape (Shim & Lee, 2011) or because they only heard descriptions of

their virtual garment simulations (Lee et al, 2012). This study was more similar to Kim and LaBat's research (2013), which asked participants to evaluate the virtual fit of pants using their own body scan image. Several key issues from Kim and LaBat's (2013) study were also identified in this research, including participant discomfort with viewing the avatar, participants being impressed with the ability to view themselves virtually, participants feeling that using the software was a fun and interesting new experience, and the perception that the avatars were more beneficial for online shopping purposes than current model images. However, the participants in this study represented a subset of the general population, people with disabilities related to body asymmetry, and were therefore different from the participants included in Kim and LaBat's (2013) research, who were able-bodied women aged 19 to 35. The researcher concluded that some consumers with body asymmetry have similar perceptions of and concerns with using 3D apparel visualization technology as people in previously studied demographic groups. Future research could involve a larger sample and/or a wider range of inclusion criteria for people with disabilities to validate these conclusions.

Perception of virtual and physical garments

Subjectivity of fit preference

Findings from the responses to the virtual and physical garments revealed that the participants had different perceptions of what a good fit entailed and how they preferred garments to fit on themselves, which has been addressed in literature (Ashdown, 2007; Ashdown et al, 2006).

Subject A tended to prefer looser garments, especially pants, while Subject B preferred more closely fitted garments and pants with a slimmer silhouette than the trousers chosen for this research. These individual preferences seemed to influence the participant's overall satisfaction

with the virtual and physical garments. Subject A said several times that she ‘loved the clothes,’ during her physical fitting while Subject B said she liked ‘the fact that they’ll be altered to fit me,’ during the physical fitting, indicating a somewhat lower level of satisfaction than Subject A showed. The researcher concluded that subjectivity of fit among consumers exists as much for people with body asymmetry as it does for the ‘standard body’ population, and that fit preference impacts the participant response to virtual garments in the 3D apparel visualization software. Fit preferences of people with disabilities has not been widely addressed in the literature, so there is little information to compare this study with.

Response to physical garments

Participant responses to physical garments were generally similar to responses to the virtual garments. Both participants saw areas of improvement in garment fit by looking at the virtual samples. Once the participants tried on their physical garments, they identified several issues with the fit they had not been able to perceive using the virtual samples, particularly with the sleeves and armhole. There were also areas of the garments that had fitting issues which were not resolved by the virtual fitting process, particularly for the back of Subject B’s shirt, which still showed folds (Figure 30 below). These issues indicate that without having a previously understood garment fit, one virtual sample and one physical sample may not be enough to arrive at a satisfactory garment fit for consumers with body asymmetry. In Subject B’s case, the style of the shirt may have contributed to the fit issues. Having only the center back seam and waist darts to manipulate may not have been enough to successfully remove the folds around the center back waist; having a shirt design with a center back seam and two side back seams may have worked better for this particular participant, or for consumers with scoliosis. Experimenting with

multiple garment styles in conjunction with disability type is a possibility worth exploring in future research.



Figure 30. Subject B shirt back, showing folds.

Participant ability to judge physical fit based on virtual garments

In this research, participants were asked to assess the fit of their virtual and physical garments at eight key points; responses to these questions were compared in the findings to provide insight into how the virtual garments could inform judgements about the fit of the physical garments.

While both participants' responses to the virtual garments matched responses to the physical garments in multiple areas, neither participant was able to use the simulation to judge the fit of the sleeves; both participants reported their physical sleeves were tight. Interestingly, both participants preferred the length and rise of their physical pant samples with the inch of seam allowance included; neither participant noticed this in the virtual garments. Based on these results, the researcher concluded that at present, a visual assessment of virtual garments alone may not be enough to help consumers with body asymmetry determine how a garment fits them in real life. However, both participants showed interest in using custom avatars and garment simulation in online shopping environments and spoke to the benefits of the technology in this

area. Future research could involve further exploration of virtual garment try-on for people with disabilities and compare perception of virtual garment fit with perception of physical garment fit. Another avenue for exploration could be applying animations to custom avatars for people with disabilities. This could provide benefit in terms of showing the garment in motion, which may give additional perspective on garment fit and functionality.

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APPENDICES

Appendix A: Informed Consent Form for Research

3D Clothing Project

Start of Block: Default Question Block

Q1 Below is a copy of the consent form that participants must sign. Please read over this form. If after reading this form you feel you do not want to participate, select Decline to exit the survey. If you feel you are willing to sign the consent form select Continue to move to the eligibility questions.
North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study/Repository: Creation of 3D Avatars for People with Disabilities, to be used in 3D Apparel Simulation

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 we can improve the fit of clothing for people with disabilities by using 3D avatars in virtual fitting.

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 you have experienced difficulties in finding clothing that fits you well. You may not want to participate in this research because it does involve body scanning and will require travel to the Wilson College of Textiles.

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 create 3D avatars that are true to the shapes of actual people so that we can use those avatars to virtually fit clothing. This will help us to improve standardization for the fit of clothing for different body types.

Am I eligible to be a participant in this study?

In order to be a participant in this study you must satisfy the following conditions:

- be age 18 or over
- have one or more of the following conditions:
 Kyphosis Lordosis Scoliosis other posture variation
 absence of upper limb, either partial or full
- able to come to the Wilson College of Textiles for two, two-hour sessions including a garment fitting
- willing to have measurements taken manually (including chest, waist, hip, inseam, outseam, neck to waist front and back, arm and shoulder length)
- willing to be scanned wearing underwear or tightfitting clothing (a changing room and complete privacy will be provided during the scanning process)
- able to stand for a maximum of two minutes in a body scanner.
- willing/able to participate in two videotaped interviews (video will not be shared publicly)
- willing to be photographed in street clothes and in sample garments (heads and recognizable features will be cropped from photos if shared in reporting of research)
- able to don and doff clothes, with assistance as necessary

You cannot participate in this study if you do not meet the above criteria.

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:

- Travel to the Wilson College of Textiles for an initial session (about two hours) during which you will
 - Participate in an interview that will be videotaped
 - Be photographed in your “street” clothes
 - Have measurements taken manually (including chest, waist, hip, inseam, outseam, neck to waist front and back, arm and shoulder length)
 - Be scanned in a body scanner designed to capture body measurements. For this procedure you will need to be able to stand for a maximum of two minutes. You will be asked to go into a private booth where you will remove your clothing except underwear, or change into tight fitting clothing.
- Travel to the Wilson College of Textiles (if randomly selected) for a second session during which you will
 - View 3D images of your custom avatar with clothing developed to fit you, and respond to questions about the virtual fitting experience (this session will be videotaped).
 - Try on a physical sample of your custom clothing and respond to questions about clothing fit (this session will be audiotaped).
 - Be photographed in these physical clothing samples.
 - Respond to final questions about the overall experience.

The total amount of time that you will be participating in this study is approximately four hours, not including travel to and from the Wilson College.

Photos and video

If you want to participate in this research, you must agree to being video recorded, photographed, and audio recorded. If you do not agree to being video recorded, photographed, and audio recorded you cannot participate in this research. Video will not be shared publicly. Heads and recognizable features will be cropped from photos if shared in reporting of research. As a part of this research, we would like your consent to video record and audio record your interviews, and to photograph you in both the initial session and in the fitting session.

I consent to be video recorded audio recorded, and photographed

I do not consent to be video recorded audio recorded, and 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 benefit is contributing to a general understanding of the potential for using 3D apparel simulation to solve sizing, fit, and wearability issues for people with disabilities.

Right to withdraw your participation

You can stop participating in this study at any time. In order to stop your participation, please contact one of the researchers using the above contact information. There will be no impact to you if you choose to withdraw your consent and stop participating.

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. 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 receive a \$25 Visa Gift Card. You will receive this compensation at your initial interview session. There will be no impact to your compensation if you choose to withdraw from the study after the first interview session.

Emergency medical treatment

If you are hurt or injured during the study session(s), the researcher will call 911 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 researchers, Anne Porterfield, japorter@ncsu.edu, 919-515-5181, Kate Annett-Hitchcock, kecarrol@ncsu.edu, 919-515-0905

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> **Consent To Participate (you will be asked to sign this form during your initial interview)** “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

- Decline (4)

- Continue to eligibility questions (5)

Skip To: End of Block If Below is a copy of the consent form that participants must sign. Please read over this form. If a... = Decline

Appendix B: Recruitment Survey Instrument



Q3 Are you willing to be body scanned wearing either underwear or tightfitting clothing? (A changing room and complete privacy will be provided during the scanning process)

- Yes (1)
- No (2)

Skip To: End of Block If Are you willing to be body scanned wearing either underwear or tightfitting clothing? (A changing... = No

Q7 Are you willing to have manual body measurements taken by our research team? (chest, waist, and hip circumferences, neck to waist front and back, arm length, inseam, outseam)

- Yes (5)
- No (6)
-

Q4 Can your disability be described as one or more of the following? Please indicate all that may apply:

- Kyphosis (1)
- Lordosis (2)
- Scoliosis (3)
- other posture variation, please describe (4)

- absence of upper limb, either partial or full (5)
- none of the above (6)

Skip To: End of Block If Can your disability be described as one or more of the following? Please indicate all that may ap... = none of the above

Q5 Are you able to get transportation to and from the Wilson College of Textiles?

- Yes (1)
- No (2)

Skip To: End of Block If Are you able to get transportation to and from the Wilson College of Textiles? = No

Q6 Are you able and willing to come to the Wilson College of Textiles during April or May 2019?

- Yes (1)
- No (2)

Skip To: End of Block If Are you able and willing to come to the Wilson College of Textiles during April or May 2019? = No

Q8 Are you willing to be interviewed, videotaped and photographed? (Our study is subject to UNC system human subject review.)

Yes (1)

No (2)

Skip To: End of Block If Are you willing to be interviewed, videotaped and photographed? (Our study is subject to UNC syst... = No

Q9 Are you be able and willing to return for a sample garment fitting at the end of June 2019? We will be randomly selecting participants for that stage of the research, so we may not need your participation in a second session, but we want to make sure you are able/willing if selected.

Yes (1)

No (2)

Skip To: End of Block If Are you be able and willing to return for a sample garment fitting at the end of June 2019? We wi... = No

Q11 Thank you for completing our survey! We'd like to contact you to set up an appointment for your interview and body-scanning. Please indicate your preferred method of contact here.

Phone (4)

Email (5)

Q18

Thank you for indicating your preferred method of contact. We will contact you through the method you indicated.

In the space below, please enter your name and contact information. If you would also be willing

to share a second method of contact you may enter that as well, just in case we need to reach you and are unsuccessful through your preferred method.

Name (1) _____

Phone (2) _____

Email (3) _____

End of Block: Default Question Block

Appendix C: Initial Interview Instrument

Demographic Information (no names please)

<p>1. Age</p> <p><input type="checkbox"/> 20 - 29 <input type="checkbox"/> 50 - 59</p> <p><input type="checkbox"/> 30 - 39 <input type="checkbox"/> 60 - 69</p> <p><input type="checkbox"/> 40 - 49 <input type="checkbox"/> 70 - 79</p>	<p>2. What is your education level?</p> <p><input type="checkbox"/> Some high school</p> <p><input type="checkbox"/> High school diploma or equivalent</p> <p><input type="checkbox"/> Some college</p> <p><input type="checkbox"/> Associate's level degree</p> <p><input type="checkbox"/> Undergraduate degree</p> <p><input type="checkbox"/> Graduate degree</p>
<p>3. Gender</p> <p><input type="checkbox"/> male <input type="checkbox"/> female</p> <p><input type="checkbox"/> prefer not to specify</p>	<p>4. Household income</p> <p><input type="checkbox"/> \$0-15,000 <input type="checkbox"/> \$15,001-30,000</p> <p><input type="checkbox"/> \$30,001-60,000 <input type="checkbox"/> over \$60,000</p>
<p>5. Apparel size (select all that apply)</p> <p>Women's:</p> <p><input type="checkbox"/> 0 <input type="checkbox"/> 14</p> <p><input type="checkbox"/> 2 <input type="checkbox"/> 16</p> <p><input type="checkbox"/> 4 <input type="checkbox"/> 18</p> <p><input type="checkbox"/> 6 <input type="checkbox"/> 20</p> <p><input type="checkbox"/> 8 <input type="checkbox"/> 22</p> <p><input type="checkbox"/> 10 <input type="checkbox"/> 24</p> <p><input type="checkbox"/> 12 <input type="checkbox"/> 26</p> <p>XXS XS S M L XL XXL</p> <p>Petite? yes/no Tall? yes/no</p> <p>Juniors? yes/no It varies</p> <p>None of the above I don't know</p> <p>Men's:</p> <p>S M L XL XXL</p> <p>Short? yes/no</p> <p>Regular? yes/no</p> <p>Tall? yes/no</p>	<p>6. Race/ethnic group</p> <p><input type="checkbox"/> African American/Black</p> <p><input type="checkbox"/> American Indian</p> <p><input type="checkbox"/> Asian</p> <p><input type="checkbox"/> Caucasian/White</p> <p><input type="checkbox"/> Hispanic/Latino</p> <p><input type="checkbox"/> Pacific Islander</p> <p><input type="checkbox"/> Other _____</p> <p><input type="checkbox"/> Prefer not to specify</p>

Discussion Questions (items in parentheses are to be used as prompts only)

General Questions

1. How would you describe your condition or disability that qualified you for this study?
2. What are some ways it impacts your daily life, especially in regards to clothing?
3. How do you spend your time? What are some things you do on a typical day? (Job, activities, hobbies, interests)
4. What are your clothing needs and preferences, based on these activities?

Style & Garment Features

1. Tell us about your experiences with wearing clothing, from selecting it for purchase through care and maintenance, as it relates to your condition.
2. How have those experiences made you feel about yourself? About clothing? About the fashion industry?
3. How would you describe your personal style?
4. Which aspect of clothing is most important to you and why? (Function, comfort, style, easy care, price, other)
5. Which aspect of clothing is least important to you and why? (Function, comfort, style, easy care, price, other)
6. How aware of current fashion trends would you say you are?
7. How important is it that your clothing is currently on trend?
8. How do you find clothing which suits your needs and your personal style?
9. What styles do you normally choose? (Dresses, tops, pants/jeans/leggings, jackets/hoodies)
10. What types of fabrics do you prefer? Why? (Cotton, wool, polyester, nylon, fleece, denim)
11. Are you generally able to find clothes in fabrics you like?
12. Are there any particular features you either look for or avoid? (Hoods, collars, cuffs, pull-overs, particular lengths, fly-front, elasticized waists)
13. Do you have any ideas about features you'd like to have that aren't offered?
14. Would you be interested in buying adaptive apparel, were it available?
15. What kinds of garments would you want adapted the most? Which would be most helpful to you? (Shirt, pants, skirt, dress, jacket, coat, leggings, underwear, gloves, socks, shoes)
16. Would you be interested in a level of concealment for any adaptive features? Why or why not?

Fit Issues

1. How do you prefer your clothing to fit? (Tight/bodycon, fitted, semi-fitted, loose, oversized)
2. Do you have any recurring problems with the fit of clothes?
3. How would you say fitting problems affect your life? Your comfort? Your confidence?
4. Have you ever had a garment custom made? What did you think of that experience?

Dressing

1. When you get dressed for a normal day, does anyone assist you with anything? If so, how do they help?
2. Which clothing items are the easiest and hardest to put on and take off? (Shirt, pants, skirt, dress, jacket, coat, leggings, underwear, gloves, socks, shoes)
3. Where do you most want to have a closure? (Front, back, side, waist, other)
4. Where do you least want to have a closure? (Front, back, side, waist, other)
5. What type of closure is easy/difficult for you? (Zip, button, snap, hook, Velcro, tie, magnet, other)
6. Do you have any challenges associated with laundering? If so, what are they?

Appendix D: Final Interview Instrument

Script for Fitting Interview (Items in parentheses are to be used as prompts only)

A. 3D Avatar and Virtual Garment Questions

“Here is an image of the 3D avatar that has been created from your body scan and dressed in a specific set of clothing that has been designed specifically for this study. ”

- a. What do you think of your 3D avatar?
- b. What do you think of the virtual garment?

“Now we are going to go through the steps of a virtual fitting where we will look at specific garment components. I can rotate the avatar, and we can zoom in and out on any area you want to see more clearly. We can also to some extent move the fabric on this garment. I’m happy to let you control the mouse if you want to do that.”

- c. Overall, what is your impression of the fit of this garment?
- d. What are some things you like about it/them?
- e. What are some things that could be improved?
- f. What do you think of the fit at the neck? (Too tight/loose, too low/high, looks good)
- g. What do you think of the fit at the shoulders? (Too tight/loose, too low/high, looks good)
- h. What do you think of the fit at the chest? (Too tight/loose, too low/high, looks good)
- i. What do you think of the fit at the sleeves? (Too tight/loose, too low/high, looks good)
- j. What do you think of the fit at the waist? (Too tight/loose, too low/high, looks good)
- k. What do you think of the fit at the hips? (Too tight/loose, too low/high, looks good)
- l. What do you think of the fit at the legs/hem? (Too tight/loose, too low/high, looks good)
- m. Do you have any final thoughts about this virtual fitting you’d like to share? I’m interested in how well you feel this virtual situation represents or might help you express your challenges or experiences with clothing fit and function.

B. Actual Garment Questions

“We would now like you to try on this garment/s. It is an exact replica of what you have just seen on the computer screen. Please let us know if you will need any assistance. [Insert any special directions, such as fastening instructions, etc.] When you are comfortable, we will have a few questions for you regarding these garment/s”

- a. What are your first impressions of the garment(s)?
- b. How do you feel wearing them?
- c. Overall, what is your impression of the fit of this garment?
- d. What are some things you like about it/them?
- e. What are some things that could be improved?

“If you are ready, we are going to take some pictures of you wearing the clothes now. These images will only be seen by the research team for data analysis purposes. If we ever use the photos for public presentation, we will crop or blur out your head so you won’t be recognized.”

“Now we are going to look at different parts of the garment and we may pull, pin, or otherwise handle the garment as we do that” (sleeves, neckline, shoulders waist, hem, etc)

- f. What do you think of the fit at the neck? (Too tight/loose, too low/high, looks good)

- g. What do you think of the fit at the shoulders? (Too tight/loose, too low/high, looks good)
- h. What do you think of the fit at the chest? (Too tight/loose, too low/high, looks good)
- i. What do you think of the fit at the sleeves? (Too tight/loose, too low/high, looks good)
- j. What do you think of the fit at the waist? (Too tight/loose, too low/high, looks good)
- k. What do you think of the fit at the hips? (Too tight/loose, too low/high, looks good)
- l. What do you think of the fit at the legs/hem? (Too tight/loose, too low/high, looks good)

C. Final Questions

“You can get changed now into your own clothes, then we have a few final questions for you before you go.”

- m. Have you had any further thoughts about clothing features or functionality since the first time you came in?
- n. How would you describe your reaction to the experience of being scanned and virtually fitted?
- o. Now that you have experienced body scanning and virtual fitting, are there ways that you can see those technologies benefitting you or being used to improve your clothing experience?
- p. Do you have any final thoughts you would like to share?

“Thank you again very much for your time! We really appreciate your contribution to this research. If you have any questions going forward please feel free to contact the research team”.

Appendix E: Virtual fitting images

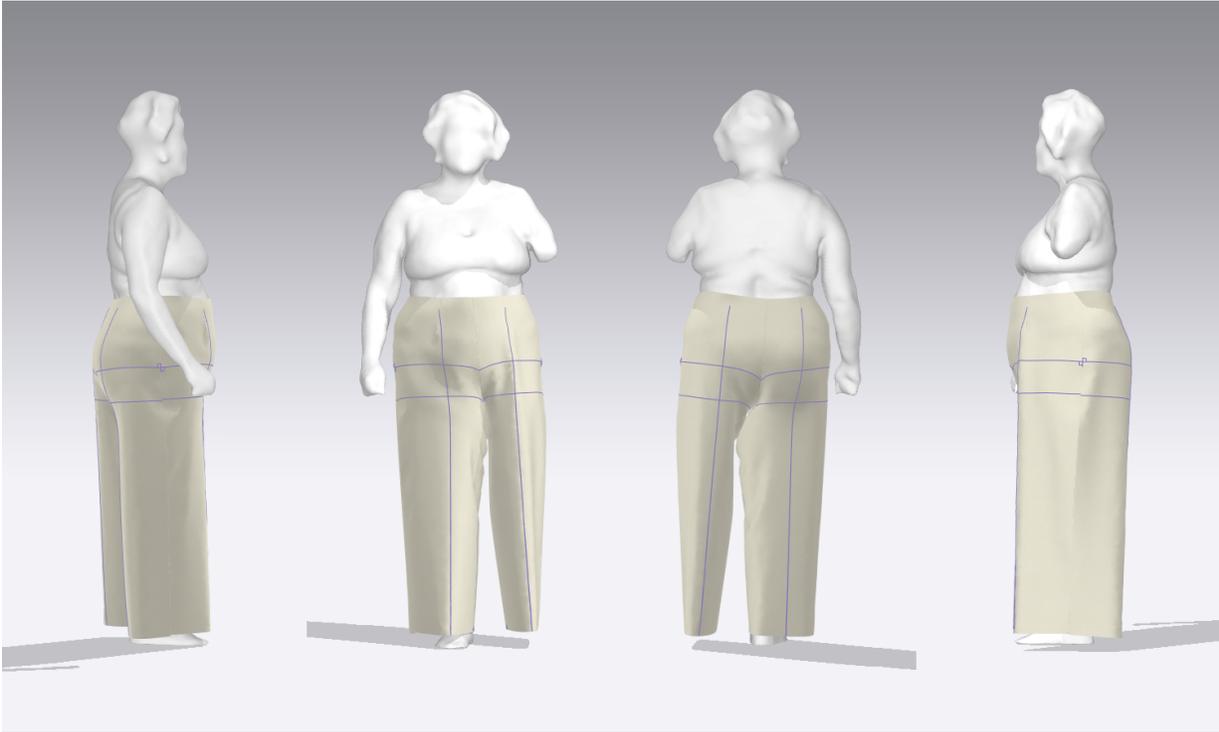


Figure 1. Subject A original pants, normal fabric view.

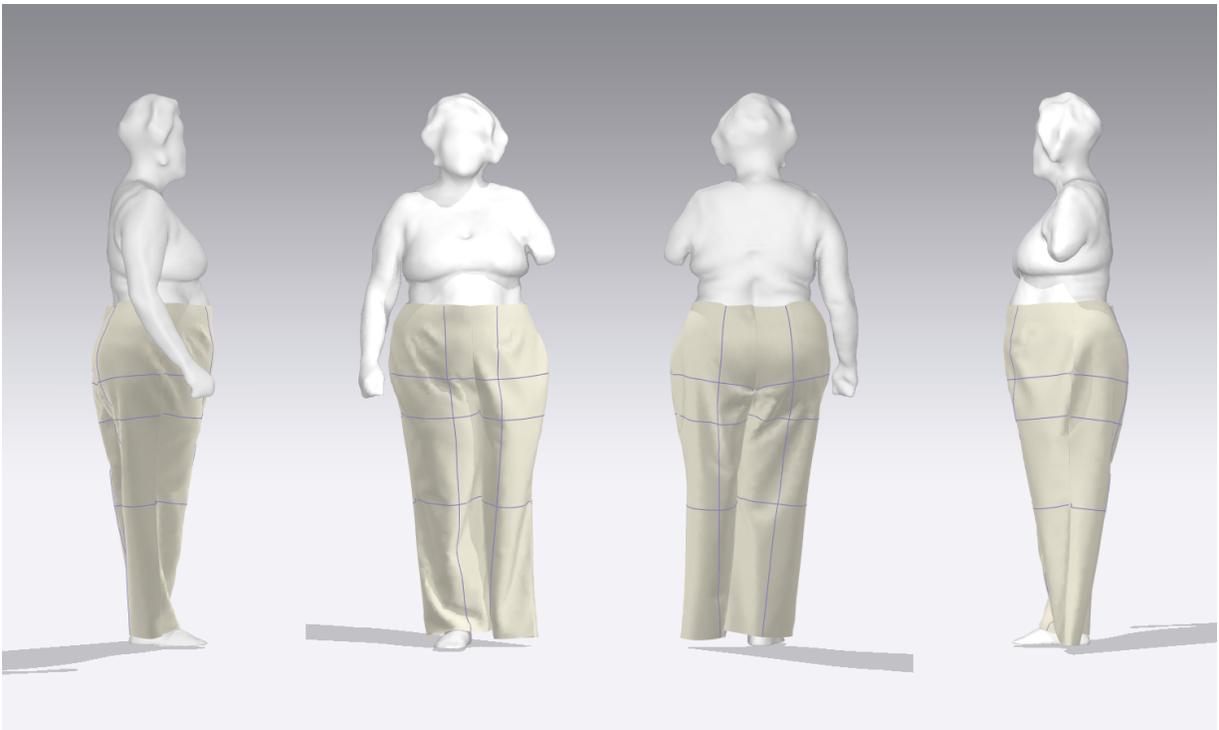


Figure 2. Subject A final pants, normal fabric view.

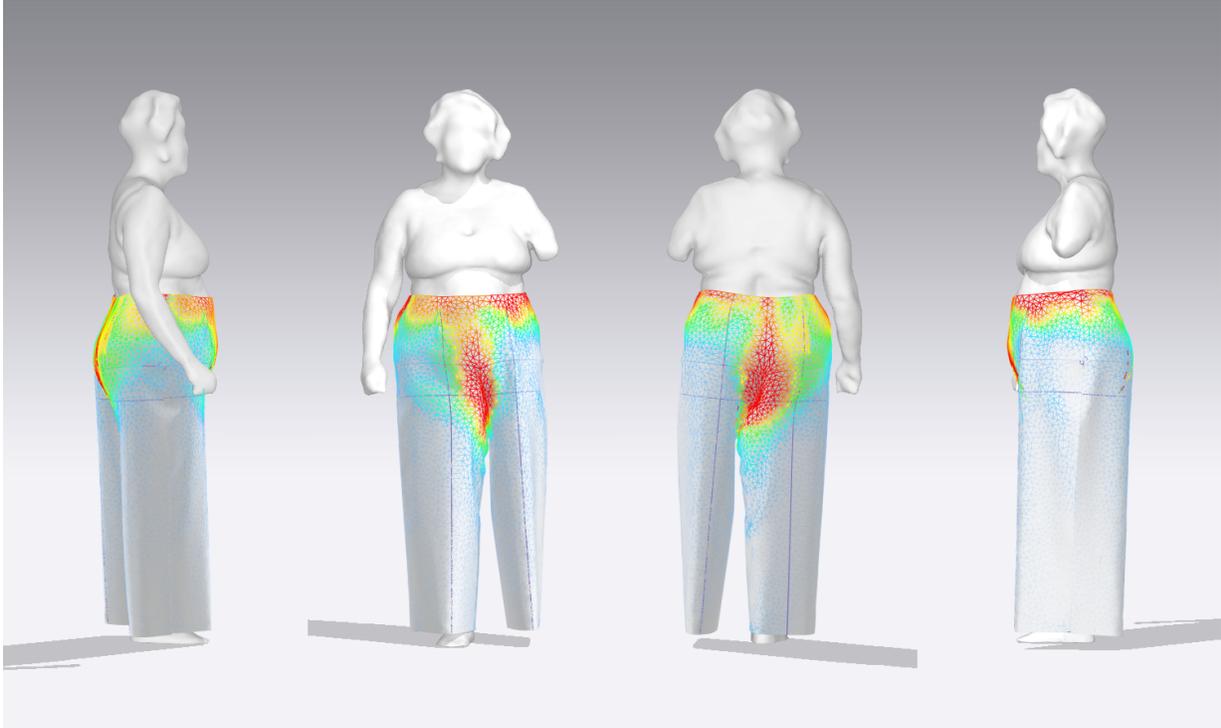


Figure 3. Subject A original pants, strain map.

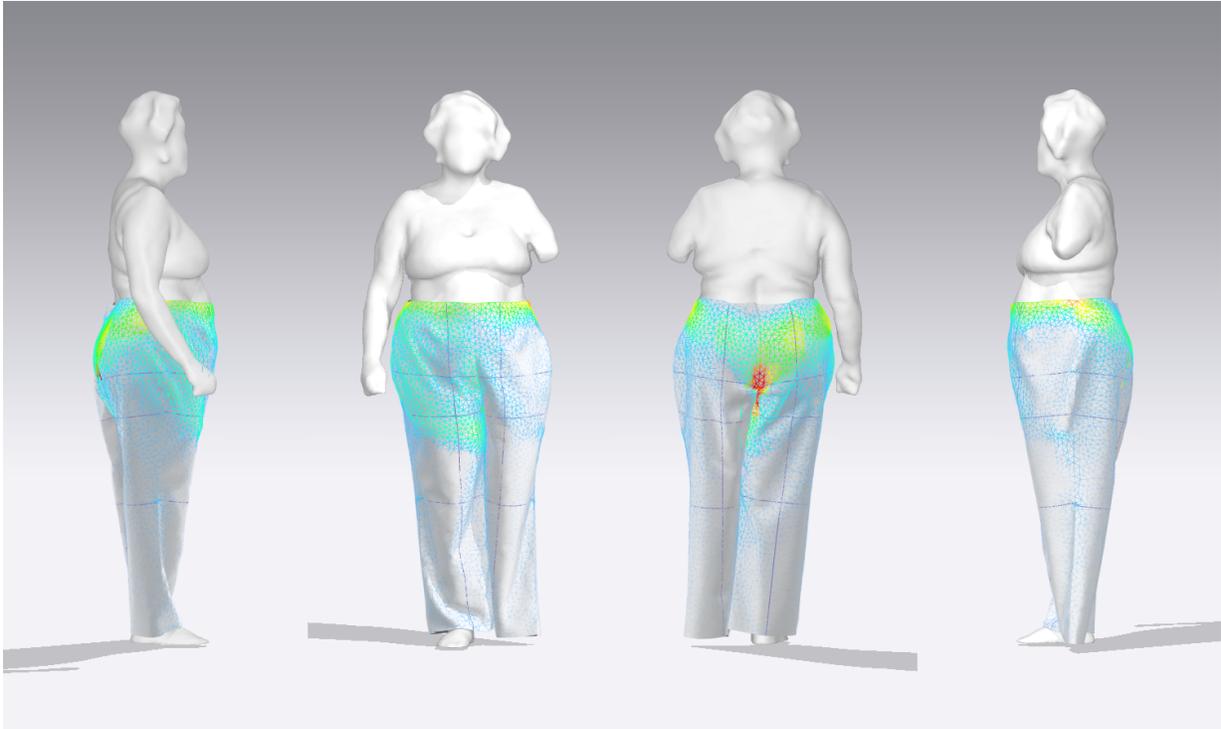
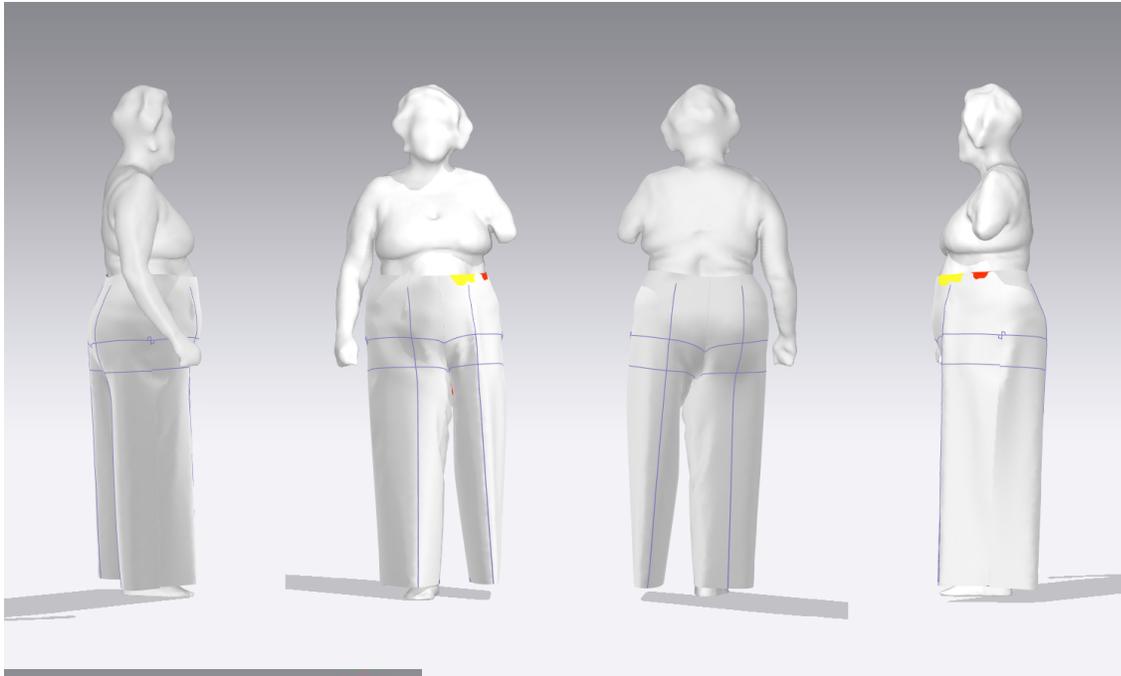


Figure 4. Subject A final pants, strain map.



Can't Wear	0.1%	3 Spots	
Tight	0.2%	4 Spots	

Figure 5. Subject A original pants, fit map.

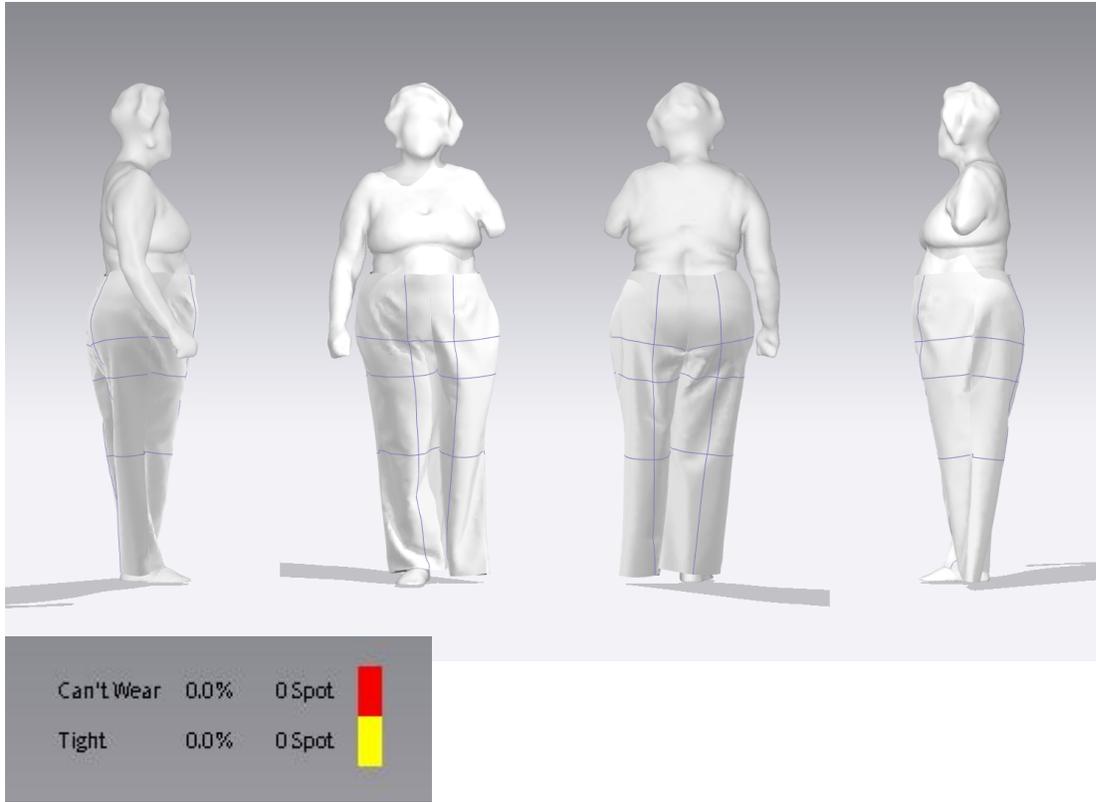


Figure 6. Subject A final pants, fit map.

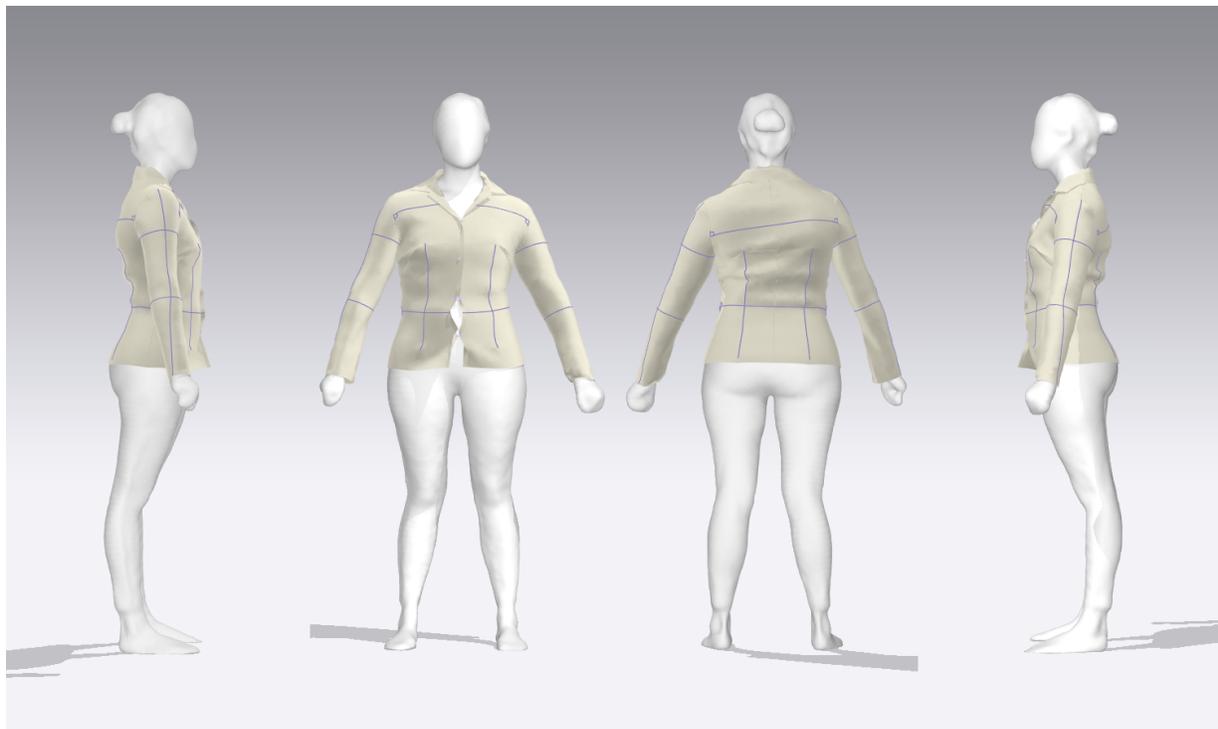


Figure 7. Subject B original shirt, normal fabric view.

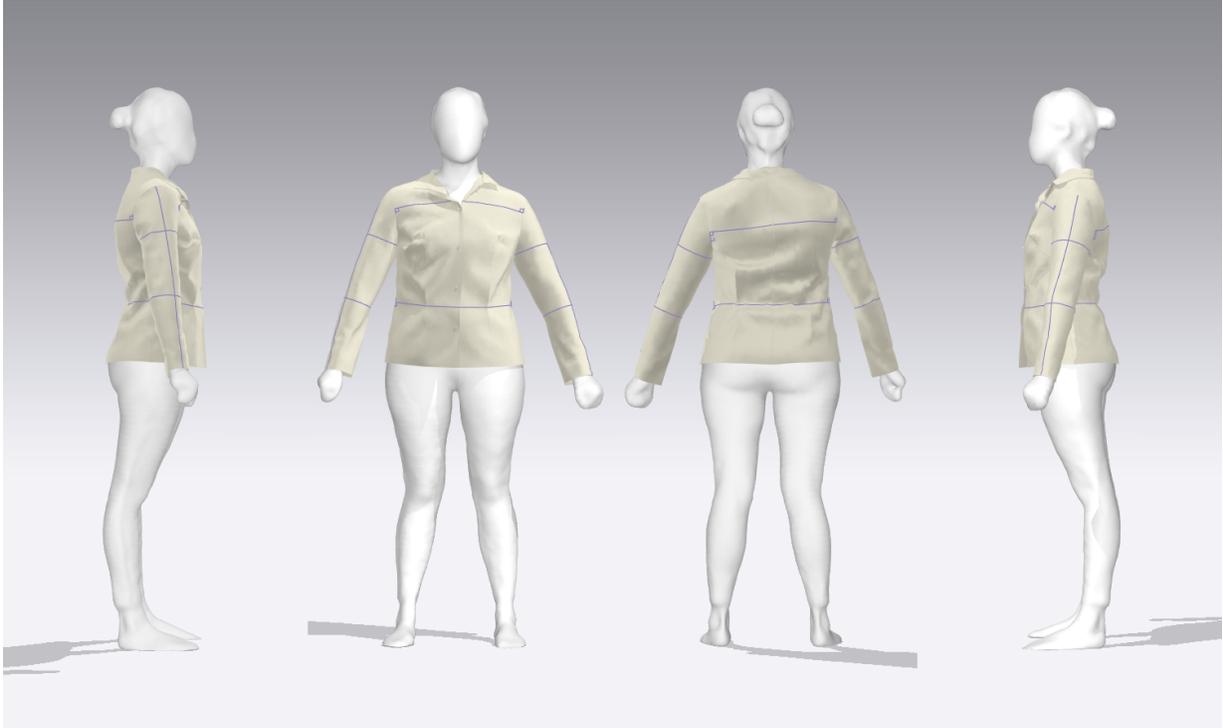


Figure 8. Subject B final shirt, normal fabric view.

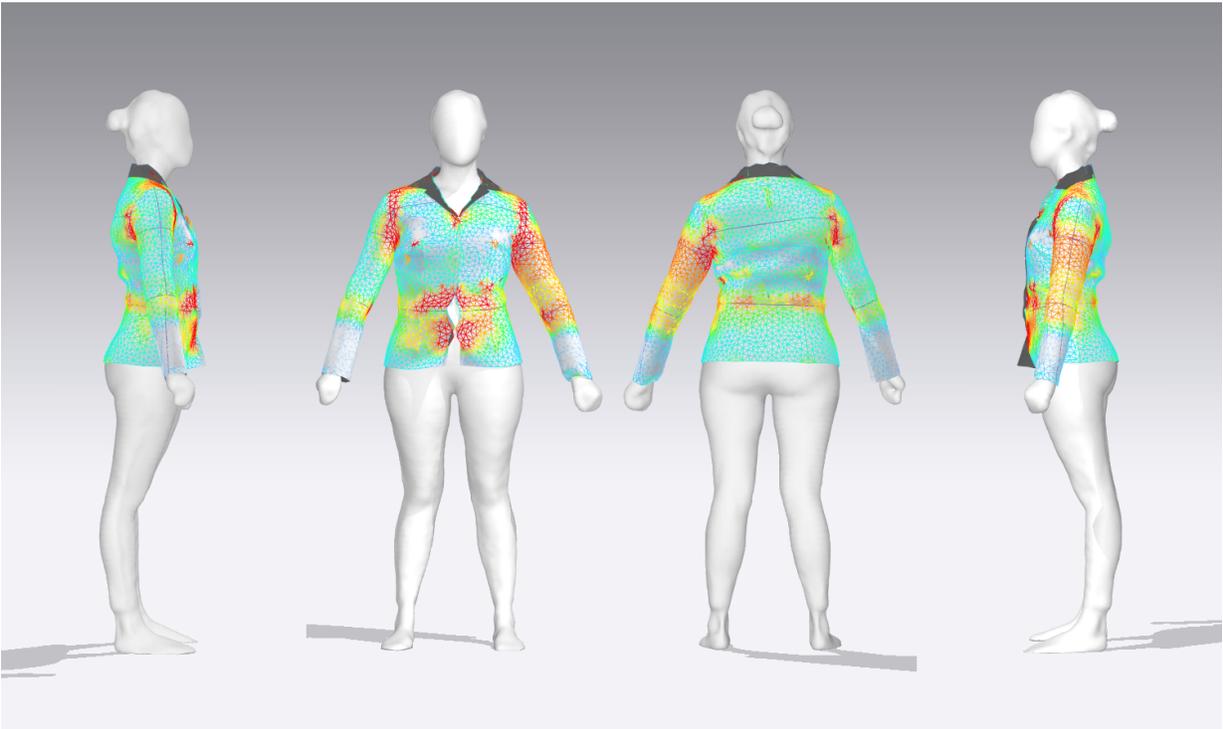


Figure 9. Subject B original shirt, strain map.

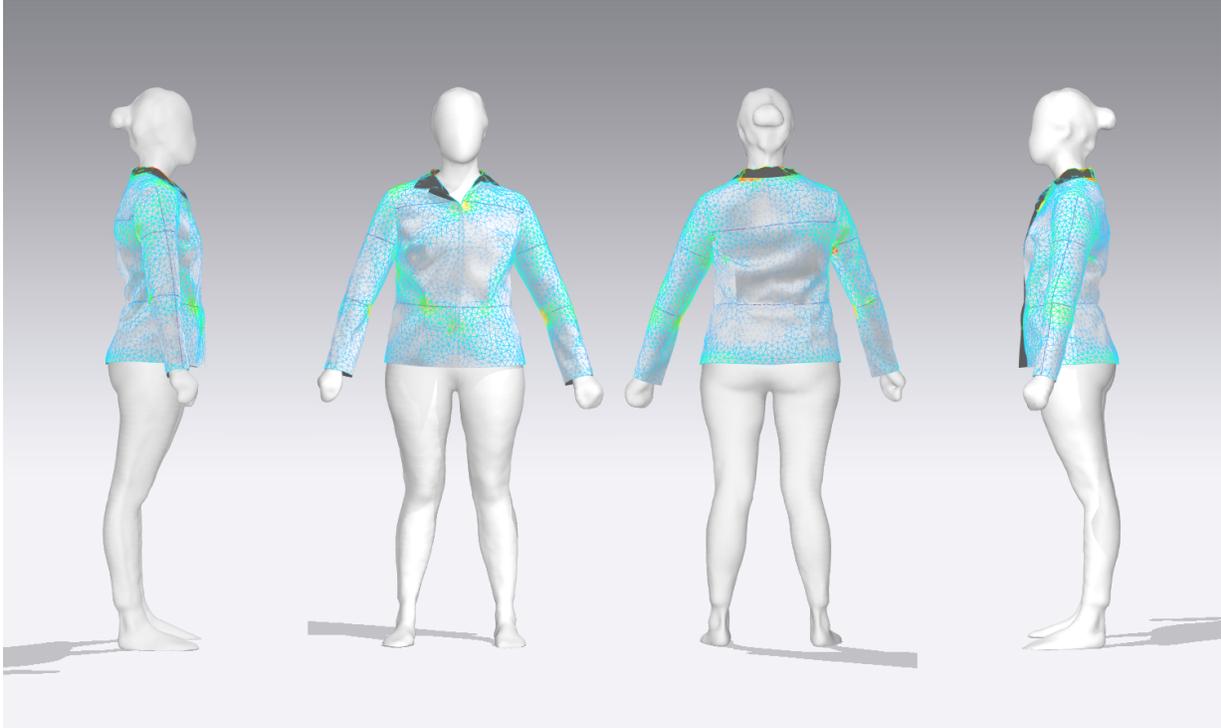


Figure 10. Subject B final shirt, strain map.

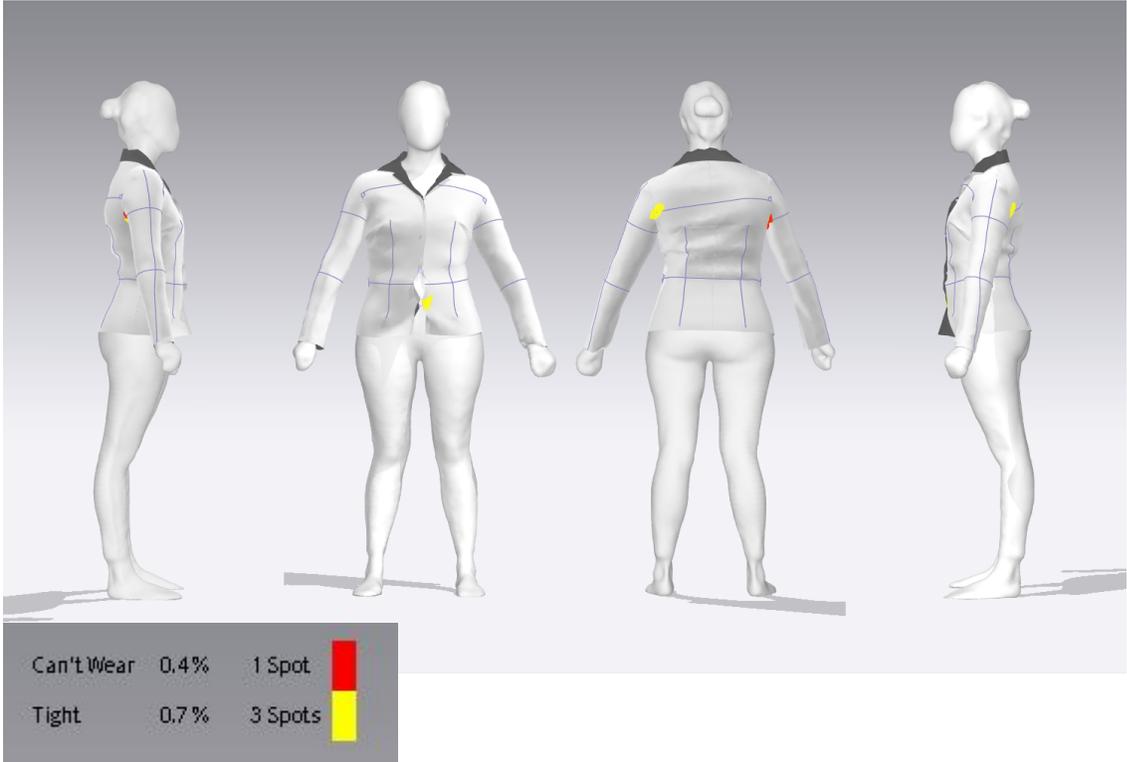


Figure 11. Subject B original shirt, fit map (top) and fit map scale (bottom).

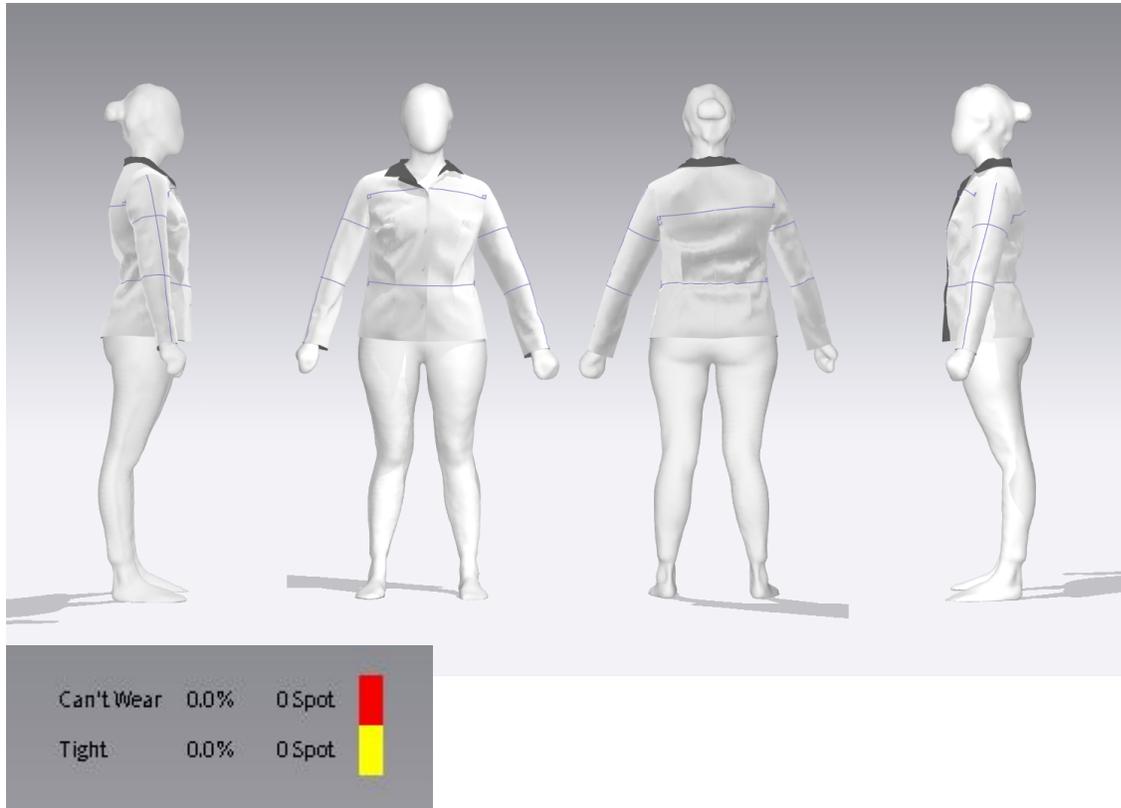


Figure 12. Subject B final shirt, fit map (top) and fit map scale (bottom).

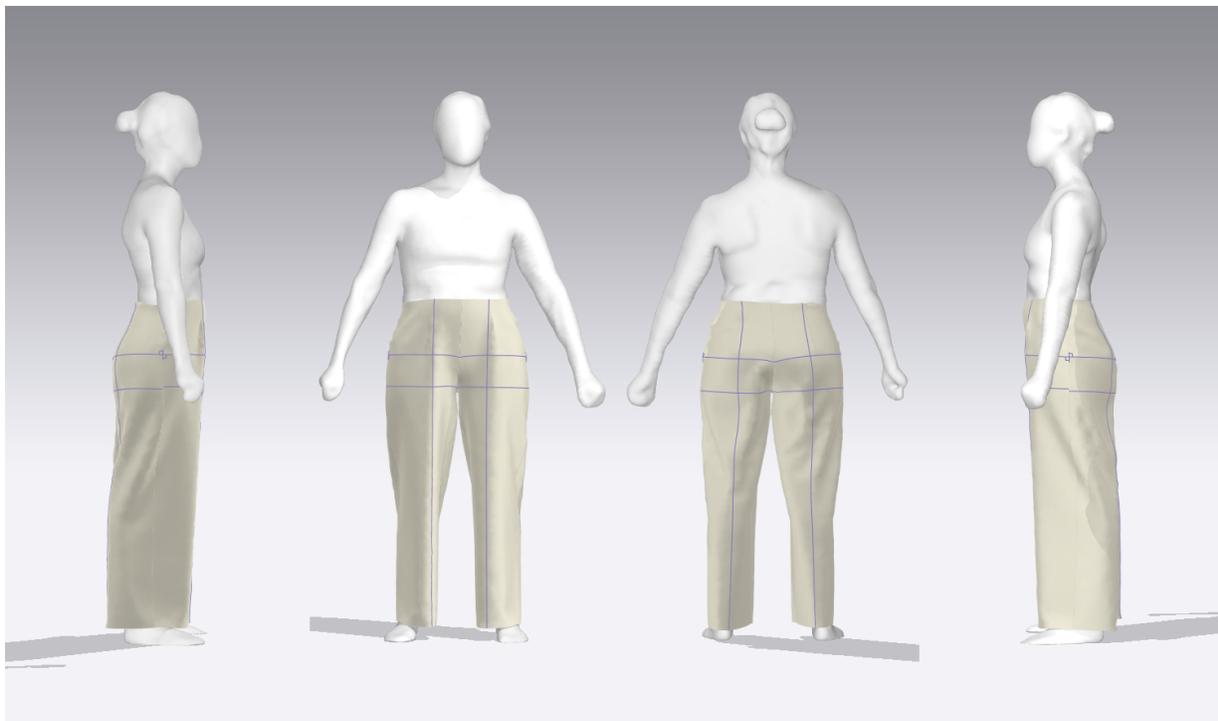


Figure 13. Subject B original pants, normal fabric view.

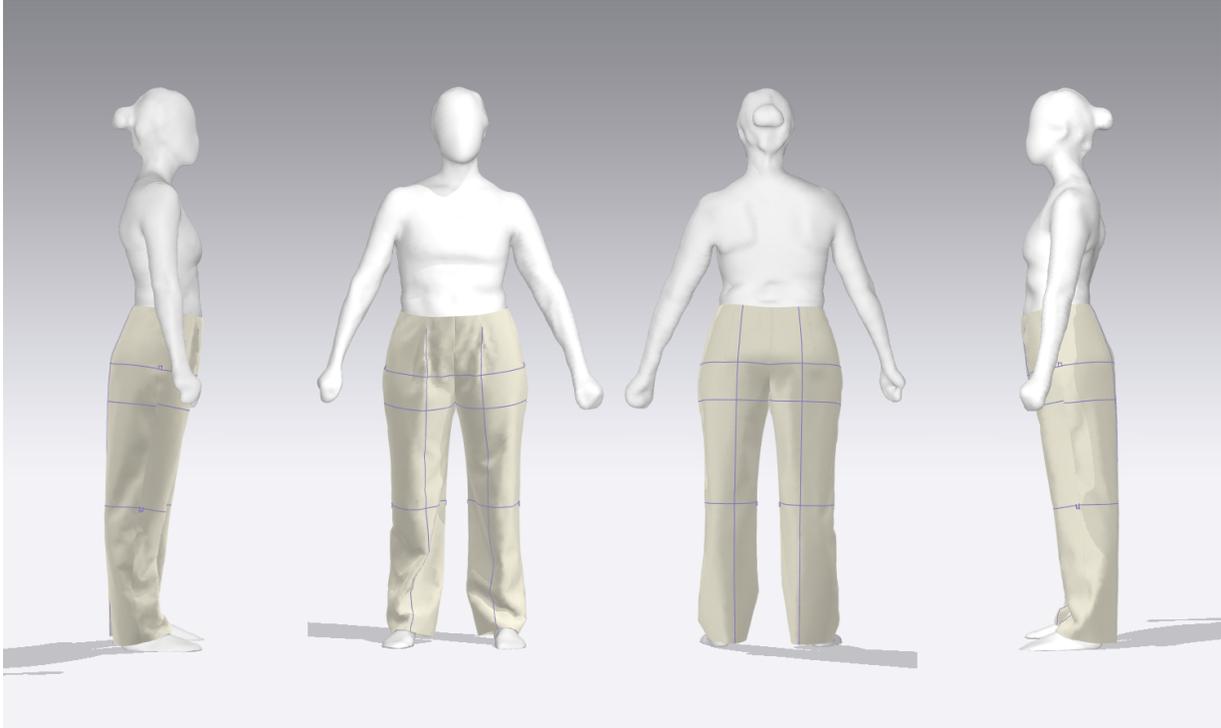


Figure 14. Subject B final pants, normal fabric view.

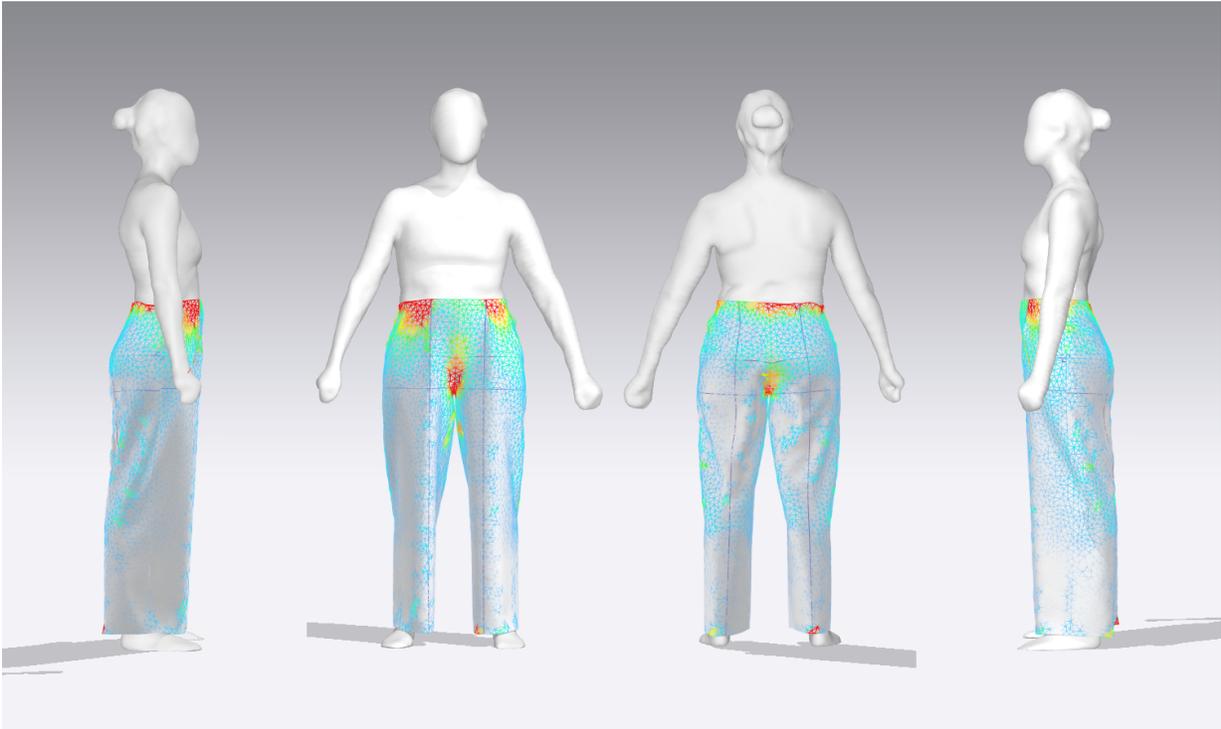


Figure 15. Subject B original pants, strain map.

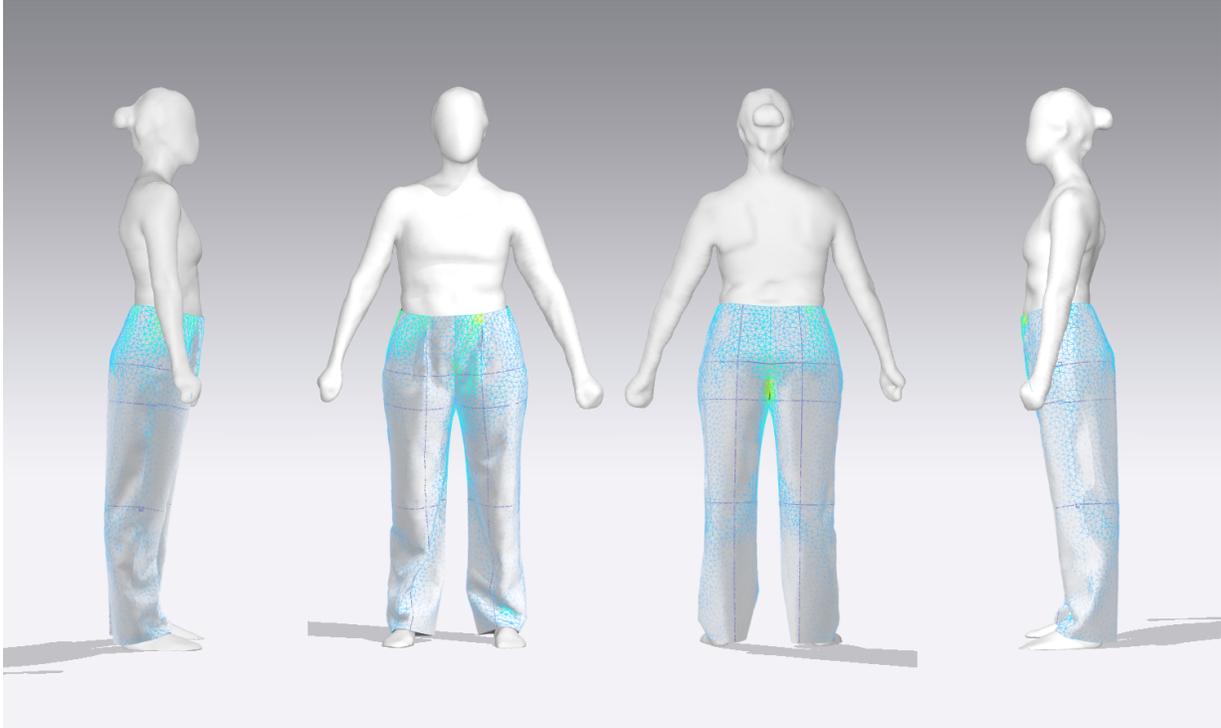


Figure 16. Subject B final pants, strain map.

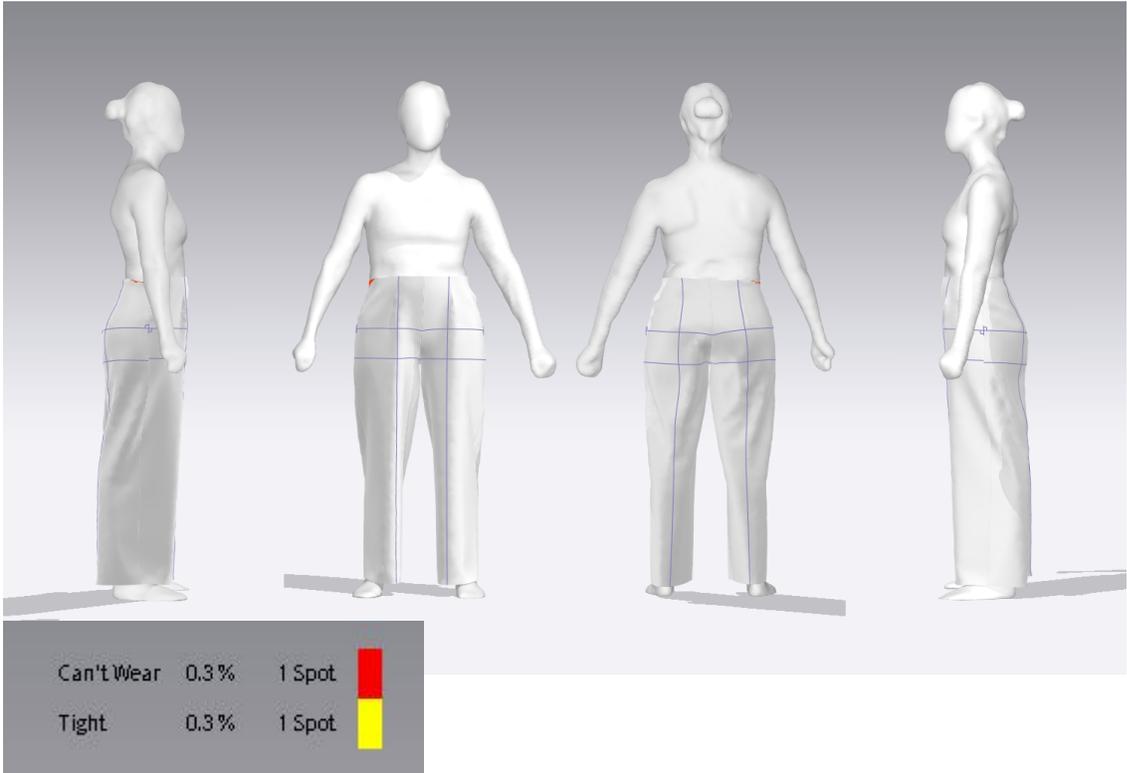


Figure 17. Subject B original pant fit map (top) and fit map scale (bottom).

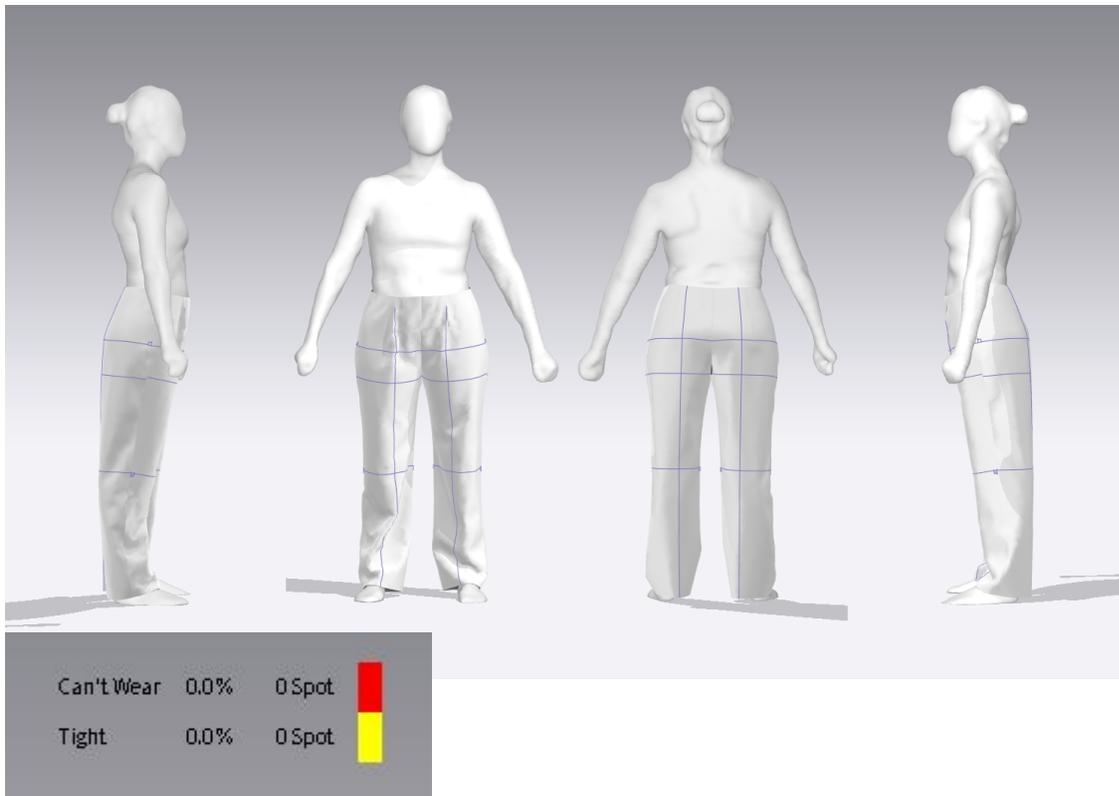


Figure 18. Subject B final pant fit map (top) and fit map scale (bottom).